



Hydraulic Charts for the Selection of Highway Culverts

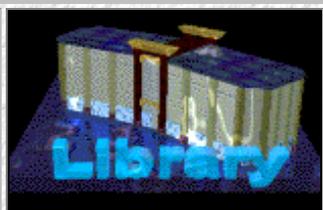
HEC 5

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HEC-5 Hydraulic Charts for the Selection of Highway Culverts



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Part I : HEC 5

Hydraulic Charts for the Selection of Highway Culverts

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Introduction

Designing highway culverts involves many factors including estimating flood peaks, hydraulic performance, structural adequacy, and overall construction and maintenance costs. This circular contains a brief discussion of the hydraulics of conventional culverts and charts for selecting a culvert size for a given set of conditions. Instructions for using the charts are provided. No attempt is made to cover all phases of culvert design. Subsequent circulars will cover culverts with modified inlets and outlets designed to increase performance or to apply to a particular location. Some approximations are made in the hydraulic design procedure for simplicity. These approximations are discussed at appropriate points throughout the circular.

For this discussion, conventional culverts include those commonly installed, such as circular, arch and oval pipes, both metal and concrete, and concrete box culverts. All such conventional culverts have a uniform barrel cross section throughout. The culvert inlet may consist of the culvert barrel projected from the roadway fill or mitered to the embankment slope. Sometimes inlets have headwalls, wingwalls, and apron slabs, or standard end sections of concrete or metal. The more common types of conventional culverts are considered in this circular.

Culvert Hydraulics

Laboratory tests and field observations show two major types of culvert flow: (1) flow with inlet control and (2) flow with outlet control. For each type of control, different factors and formulas are used to compute the hydraulic capacity of a culvert. Under inlet control, the cross-sectional area of the culvert barrel, the inlet geometry and the amount of headwater or ponding at the entrance are of primary importance. Outlet control involves the additional consideration of the elevation of the tailwater in the outlet channel and the slope, roughness and length of the culvert barrel.

It is possible by involved hydraulic computations to determine the probable type of flow under which a culvert will operate for a given set of conditions. The need for making these computations may be avoided, however, by computing headwater depths from the charts in this circular for both inlet control and outlet control and then using the higher value to indicate the type of control and to determine the headwater depth. This method of determining the type of control is accurate except for a few cases where the headwater is approximately the same for both types of control.

Both inlet control and outlet control types of flow are discussed briefly in the following paragraphs and procedures for the use of the charts are given.

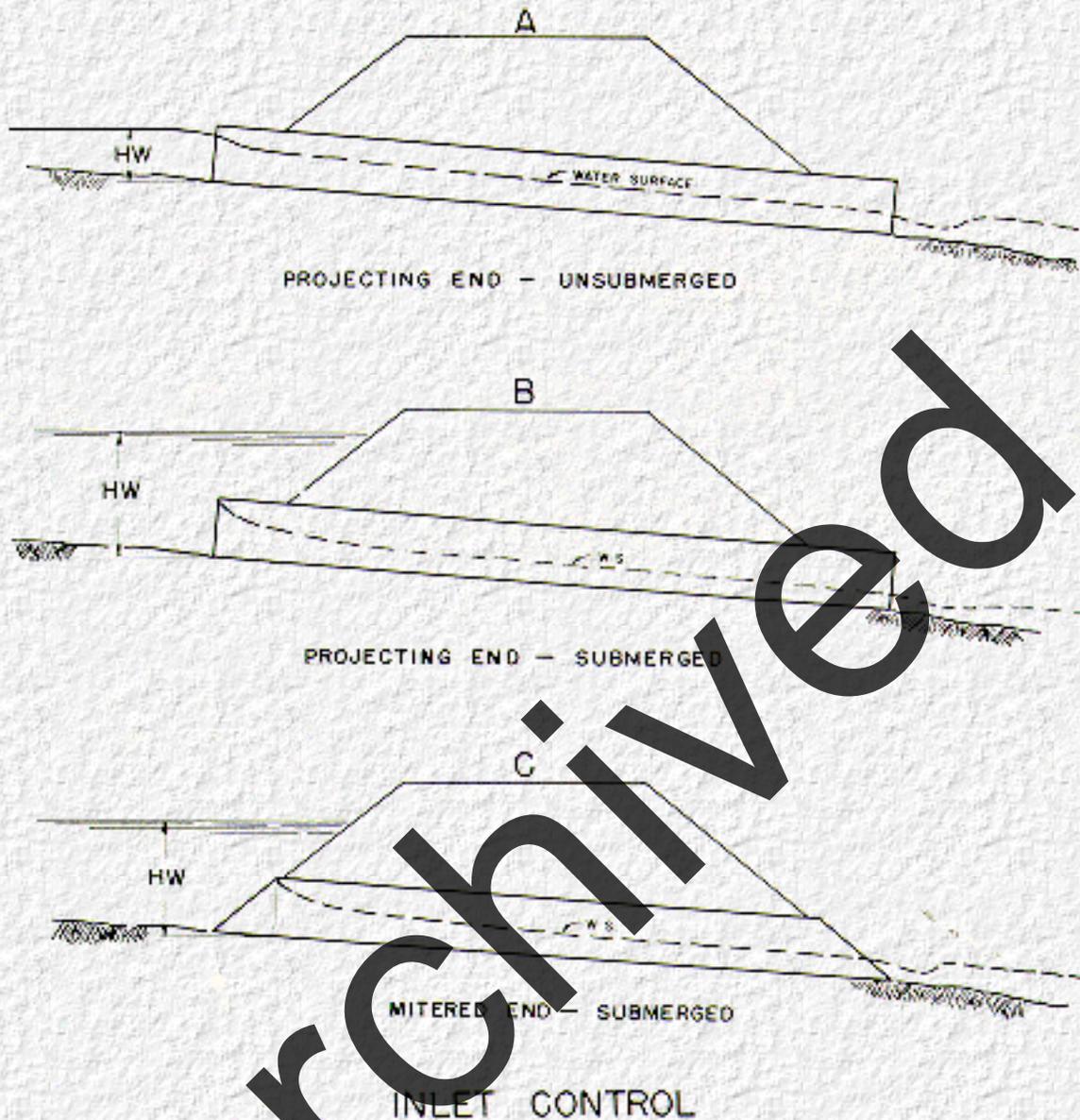


Figure 1. Inlet Control

Culverts Flowing with Inlet Control

Inlet control means that the discharge capacity of a culvert is controlled at the culvert entrance by the depth of headwater (HW) and the entrance geometry, including the barrel shape and cross-sectional area, and the type of inlet edge. Sketches of inlet-control flow for both unsubmerged and submerged projecting entrances are shown in [Figure 1A](#) and [Figure 1B](#). [Figure 1C](#) shows a mitered entrance flowing under a submerged condition with inlet control.

In inlet control the roughness and length of the culvert barrel and outlet conditions (including depth of tailwater) are not factors in determining culvert capacity. An increase in barrel slope reduces headwater to a small degree and any correction for slope can be neglected for

conventional or commonly used culverts flowing with inlet control.

In all culvert design, headwater or depth of ponding at the entrance to a culvert is an important factor in culvert capacity. The headwater depth (or headwater HW) is the vertical distance from the culvert invert at the entrance to the energy line of the headwater pool (depth + velocity head). Because of the low velocities in most entrance pools and the difficulty in determining the velocity head for all flows, the water surface and the energy line at the entrance are assumed to be coincident, thus the headwater depths given by the inlet control charts in this circular can be higher than will occur in some installations. For the purposes of measuring headwater, the culvert invert at the entrance is the low point in the culvert opening at the beginning of the full cross-section of the culvert barrel.

Headwater-discharge relationships for the various types of circular and pipe-arch culverts flowing with inlet control are based on laboratory research with models and verified in some instances by prototype tests. This research is reported in National Bureau of Standards Report No. 4444 entitled "Hydraulic Characteristics of Commonly Used Pipe Entrances", by John L. French and "Hydraulics of Conventional Highway Culverts", by H. G. Bossy (Presented at the Tenth National Conference, Hydraulics Division, ASCE, August 1961.) Experimental data for box culverts with headwalls and wingwalls were obtained from an unpublished report of the U. S. Geological Survey.

These research data were analyzed and nomographs for determining culvert capacity for inlet control were developed by the Division of Hydraulic Research, Bureau of Public Roads. These nomographs, [Charts 1 through 6](#), give headwater-discharge relationships for most conventional culverts flowing with inlet control through a range of headwater depths and discharges. [Chart 7](#), discussed in Part I, is included in this revised edition to stress the importance of improving the inlets of culverts flowing with inlet control.

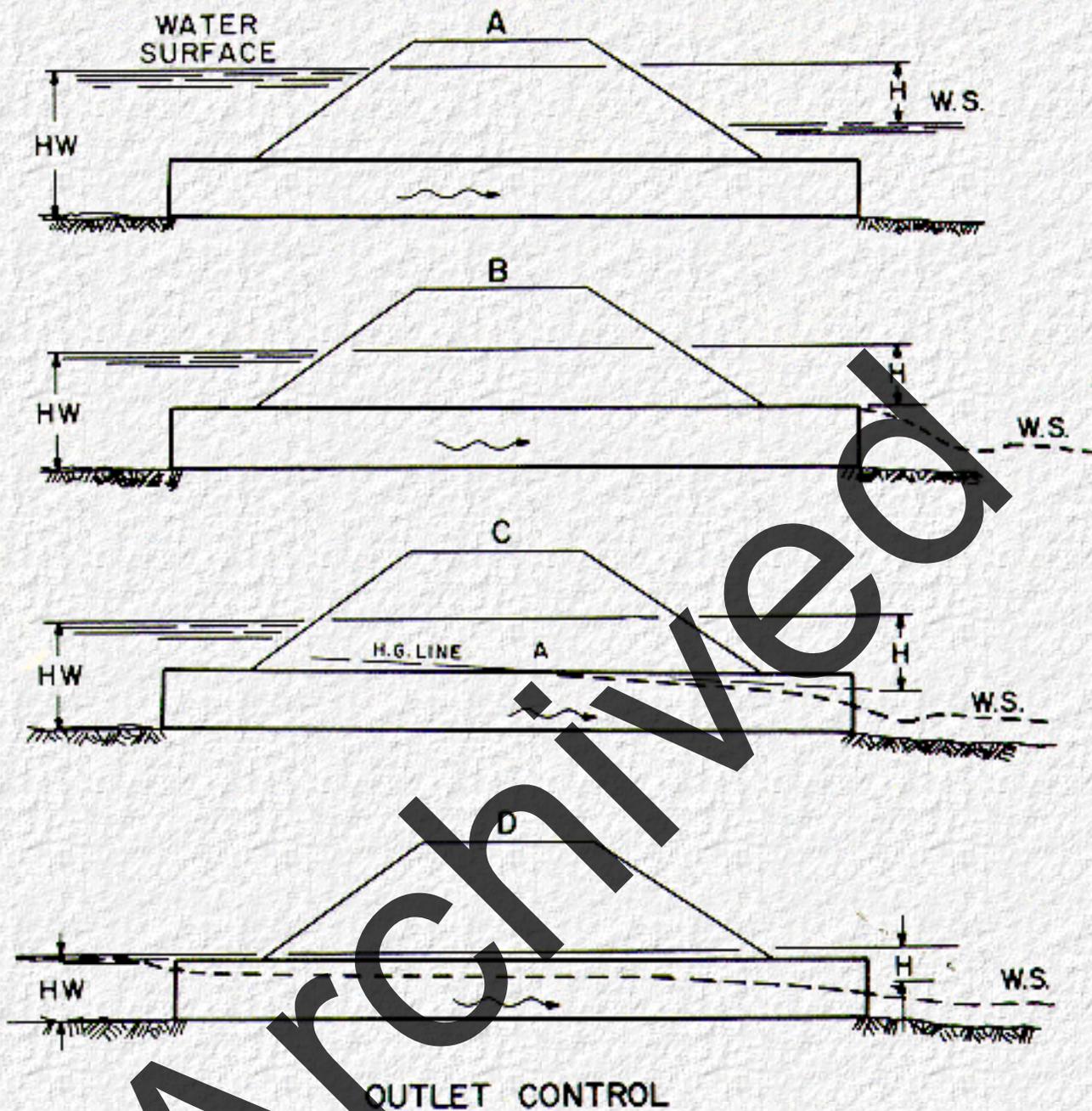


Figure 2. Outlet Control

Culverts Flowing with Outlet Control

Culverts flowing with outlet control can flow with the culvert barrel full or part full for part of the barrel length or for all of it, (see [Figure 2](#)). If the entire cross section of the barrel is filled with water for the total length of the barrel, the culvert is said to be in full flow or flowing full, [Figure 2A](#) and [Figure 2B](#). Two other common types of outlet-control flow are shown in [Figure 2C](#) and [Figure 2D](#). The procedures given in this circular provide methods for the accurate determination of headwater depth for the flow conditions shown in [Figure 2A](#), [Figure 2B](#) and [Figure 2C](#). The

method given for the part full flow condition, [Figure 2D](#), gives a solution for headwater depth that decreases in accuracy as the headwater decreases.

The head H ([Figure 2A](#)) or energy required to pass a given quantity of water through a culvert flowing in outlet control with the barrel flowing full throughout its length is made up of three major parts. These three parts are usually expressed in feet of water and include a velocity head H_v , an entrance loss H_e , and a friction loss H_f . This energy is obtained from ponding of water at the entrance and expressed in equation form

$$H = H_v + H_e + H_f \quad (1)$$

The velocity head H_v equals $\frac{V^2}{2g}$ where V is the mean or average velocity in the culvert barrel.

(The mean velocity is the discharge Q , in cfs, divided by the cross-sectional area A , in sq. ft., of the barrel.)

The entrance loss H_e depends upon the geometry of the inlet edge. This loss is expressed as a coefficient k_e times the barrel velocity head or $H_e = k_e \frac{V^2}{2g}$. The entrance loss coefficients k_e

for various types of entrances when the flow is in outlet control are given in [Appendix B, Table 1](#).

The friction loss H_f is the energy required to overcome the roughness of the culvert barrel. H_f can be expressed in several ways. Since most highway engineers are familiar with Manning's n the following expression is used:

$$H_f = \left[\frac{29n^2 L}{R^{1.33}} \right] \frac{V^2}{2g}$$

where

n = Manning's friction factor (see nomographs and [Part II](#) for values)

L = length of culvert barrel (ft)

V = mean velocity of flow in culvert barrel (ft/sec)

g = acceleration of gravity, 32.2 (ft/sec²)

R = hydraulic radius or $\frac{A}{WP}$ (ft)

where

A = area of flow for full cross-section (sq. ft)

WP = wetted perimeter (ft)

Substituting in [Equation 1](#) and simplifying, we get for full flow

$$H = \left[1 + k_e + \frac{29n^2L}{R^{1.33}} \right] \frac{V^2}{2g} \quad (2)$$

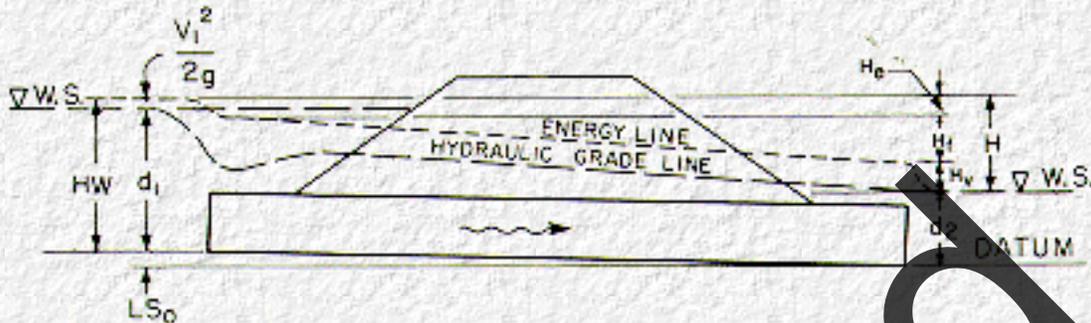


Figure 3

[Figure 3](#) shows the terms of [Equation 2](#), the energy line, the hydraulic grade line and the headwater depth, HW. The energy line represents the total energy at any point along the culvert barrel. The hydraulic grade line, sometimes called the pressure line, is defined by the elevations to which water would rise in small vertical pipes attached to the culvert wall along its length. The energy line and the pressure line are parallel over the length of the barrel except in the immediate vicinity of the inlet where the flow contracts and re-expands. The difference in elevation between these two lines is the velocity head, $\frac{V^2}{2g}$.

The expression for H is derived by equating the total energy upstream from the culvert entrance to the energy just inside the culvert outlet with consideration of all the major losses in energy. By referring to [Figure 3](#) and using the culvert invert at the outlet as a datum, we get:

$$d_1 + \frac{V_1^2}{2g} + LS_0 = d_2 + H_v + H_e + H_f$$

where

d_1 and d_2 = depths of flow as shown in [Figure 3](#)

$\frac{V_1^2}{2g}$ = velocity head in entrance pool

LS_0 = length of culvert times barrel slope

then

$$d_1 + \frac{v_1^2}{2g} + LS_0 - d_2 = H_v + H_e + H_f$$

and

$$H = d_1 + \frac{v_1^2}{2g} + LS_0 - d_2 = H_v + H_e + H_f$$

From the development of this energy equation and [Figure 3](#), head H is the difference between the elevations of the hydraulic grade line at the outlet and the energy line at the inlet. Since the velocity head in the entrance pool is usually small under ponded conditions, the water surface or headwater pool elevation can be assumed to equal the elevation of the energy line. Thus headwater elevations and headwater depths, as computed by the methods given in this circular, for outlet control, can be higher than might occur in some installations. Headwater depth is the vertical distance from the culvert invert at the entrance to the water surface, assuming the water surface (hydraulic grade line) and the energy line to be coincident, $d_1 +$

$$\frac{v_1^2}{2g}$$

in [Figure 3](#).

[Equation 2](#) can be solved for H readily by the use of the full-flow nomographs, [Charts 8 through 14](#). Each nomograph is drawn for a particular barrel shape and material and a single value of n as noted on the respective charts. These nomographs can be used for other values of n by modifying the culvert length as directed in the instructions ([Part III](#)) for the use of the full-flow nomographs.

In culvert design the depth of headwater HW or the elevation of the ponded water surface is usually desired. Finding the value of H from the nomographs or by [Equation 2](#) is only part of the solution for this headwater depth or elevation. In the case of [Figure 2A](#) or [Figure 3](#), where the outlet is totally submerged, the headwater pool elevation (assumed to be the same elevation as the energy line) is found by adding H to the elevation of the tailwater. The headwater depth is the difference in elevations of the pool surface and the culvert invert at the entrance.

When the tailwater is below the crown of the culvert, the submerged condition discussed above no longer exists and the determination of headwater is somewhat more difficult. In discussing outlet-control flow for this condition, tailwater will be assumed to be so low that it has no effect on the culvert flow. (The effect of tailwater will be discussed later.) The common types of flow for the low tailwater condition are shown in [Figure 2B](#), [Figure 2C](#) and [Figure 2D](#). Each of these flow conditions are dependent on the amount of discharge and the shape of the culvert cross section. Each condition will be discussed separately.

Full flow at the outlet, [Figure 2B](#), will occur only with the higher rates of discharge. [Charts 15 through 20](#) are provided to aid in determining this full flow condition. The curves shown on

these charts give the depth of flow at the outlet for a given discharge when a culvert is flowing with outlet control. This depth is called critical depth d_c . When the discharge is sufficient to give a critical depth equal to the crown of the culvert barrel, full flow exists at the outlet as in [Figure 2B](#). The hydraulic grade line will pass through the crown of the culvert at the outlet for all discharges greater than the discharge causing critical depth to reach the crown of the culvert. Head H can be measured from the crown of the culvert in computing the water surface elevation of the headwater pool.

When critical depth falls below the crown of the culvert at the outlet, the water surface drops as shown in either [Figure 2C](#) or [Figure 2D](#), depending again on the discharge. To accurately determine headwater for these conditions, computations for locating a backwater curve are usually required. These backwater computations are tedious and time consuming and they should be avoided if possible. Fortunately, headwater for the flow condition shown in [Figure 2C](#) can be solved by using the nomographs and the instructions given in this circular.

For the condition shown in [Figure 2C](#), the culvert must flow full for part of its length. The hydraulic grade line for the portion of the length in full flow will pass through a point where the water breaks with the top of the culvert as represented by point A in [Figure 2C](#). Backwater computations show that the hydraulic grade line if extended as a straight line will cut the plane of the outlet cross section at a point above critical depth (water surface). This point is at a height approximately equal to one half the distance between critical depth and the crown of the culvert. The elevation of this point can be used as an equivalent hydraulic grade line and H , as determined by [Equation 2](#) or the nomographs, can be added to this elevation to find the water surface elevation of the headwater pool.

The full flow condition for part of the barrel length, [Figure 2C](#), will exist when the headwater depth HW , as computed from the above headwater pool elevation, is equal to or greater than the quantity

$$D + (1 + k_e) \frac{V^2}{2g}$$

where V is the mean velocity for the full cross section of the barrel; k_e , the entrance loss coefficient; and D , the inside height of the culvert. If the headwater is less than the above value, a free water surface, [Figure 2D](#), will extend through the culvert barrel.

The part full flow condition of [Figure 2D](#) must be solved by a backwater computation if accurate headwater depths are desired. Details for making this computation are not given in this circular. Instead the solution used is the same as that given for the flow condition of [Figure 2C](#), with the reservation that headwater depths become less accurate as the discharge for a particular culvert decreases. Generally, for design purposes, this method is satisfactory for headwater depths above $0.75D$, where D is the height of the culvert barrel. Culvert capacity charts found in [Hydraulic Engineering Circular No. 10](#) give a more accurate and easy solution for this free surface flow condition.

Headwater depth HW can be expressed by a common equation for all outlet-control conditions, including all depths of tailwater. This is accomplished by designating the vertical dimension from the culvert invert at the outlet to the elevation from which H is measured as h_o . The headwater depth HW equation is

$$HW = H + h_o - LS_o \quad (3)$$

All the terms in this equation are in feet. H is computed by [Equation 2](#) or found from the full-flow nomographs. L is the length of culvert in feet and S_o the barrel slope in ft. per ft. The distance h_o is discussed in the following paragraphs for the various conditions of outlet-control flow. Headwater HW is the distance in feet from the invert of the culvert at the inlet to the water surface of the headwater pool.

When the elevation of the water surface in the outlet channel is equal, to or above the elevation of the top of the culvert opening at the outlet, [Figure 2A](#), h_o is equal to the tailwater depth. Tailwater depth TW is the distance in feet from the culvert invert at the outlet to the water surface in the outlet channel. The relationship of HW to the other terms in [Equation 3](#) is illustrated in [Figure 4](#).

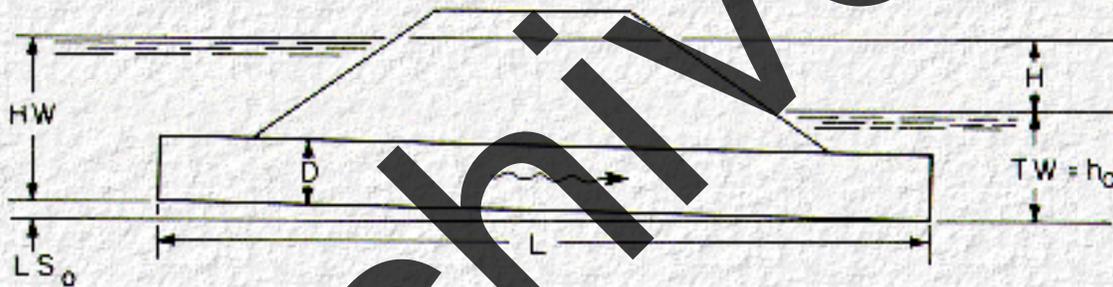


Figure 4

If the tailwater elevation is below the top of the culvert opening at the outlet, [Figure 2B](#), [Figure 2C](#), and [Figure 2D](#), h_o is more difficult to determine. The discharge, size and shape of culvert, and the TW must be considered. In these cases, h_o is the greater of two values (1) TW depth as defined above or (2) $\frac{d_c + D}{2}$. The latter dimension is the distance to the equivalent

hydraulic grade line discussed previously. In this fraction d_c is the critical depth, as read from [Charts 15 through 20](#) and D is the culvert height. The value of d_c can never exceed D, making the upper limit of this fraction equal to D. Where TW is the greater of these two values, critical depth is submerged sufficiently to make TW effective in increasing the headwater. The sketch in [Figure 5](#) shows the terms of [Equation 3](#) for this low tailwater condition. [Figure 5](#) is drawn similar to [Figure 2C](#), but a change in discharge can change the water surface profile to that of [Figure 2B](#) or [Figure 2D](#).

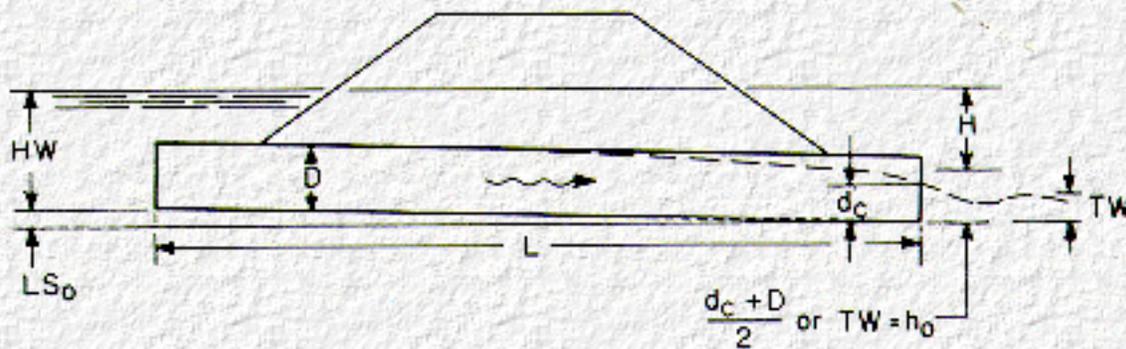


Figure 5

Computing Depth of Tailwater

In culverts flowing with outlet control, tailwater can be an important factor in computing both the headwater depth and the hydraulic capacity of a culvert. Thus, in many culvert designs, it becomes necessary to determine tailwater depth in the outlet channel.

Much engineering judgment and experience is needed to evaluate possible tailwater conditions during floods. A field inspection should be made to check on downstream controls and to determine water stages. Oftentimes tailwater is controlled by a downstream obstruction or by water stages in another stream. Fortunately, most natural channels are wide compared to the culvert and the depth of water in the natural channel is considerably less than critical depth, thus the tailwater is ineffective and channel depth computations are not always warranted.

An approximation of the depth of flow in a natural stream (outlet channel) can be made by using Manning's equation if the channel is reasonably uniform in cross section, slope and roughness. Values of n for natural streams for use in Manning's equation may be found in [Table 2](#), in [Appendix B](#). If the water surface in the outlet channel is established by downstream controls, other means must be found to determine the tailwater elevation. Sometimes this necessitates a study of the stage-discharge relationship of another stream into which the stream in question flows or the securing of data on reservoir elevations if a storage dam is involved.

Velocity of Culvert Flow

A culvert, because of its hydraulic characteristics, increases the velocity of flow over that in the natural channel. High velocities are most damaging just downstream from the culvert outlet and the erosion potential at this point is a feature to be considered in culvert design.

Energy dissipators for channel flow have been investigated in the laboratory and many have been constructed, especially in irrigation channels. Designs for highway use have been developed and constructed at culvert outlets. All energy dissipators add to the cost of a culvert,

therefore, they should be used only to prevent or to correct a serious erosion problem. (See [references 4 and 5.](#))

The judgment of engineers working in a particular area is required to determine the need for energy dissipators at culvert outlets. As an aid in evaluating this need, culvert outlet velocities should be computed. These computed velocities can be compared with outlet velocities of alternate culvert designs, existing culverts in the area, or the natural stream velocities. In many streams the maximum velocity in the main channel is considerably higher than the mean velocity for the whole channel cross-section. Culvert outlet velocities should be compared with maximum stream velocities in determining the need for channel protection. A change in size of culvert does not change outlet velocities appreciably in most cases.

Outlet velocities for culverts flowing with inlet control may be approximated by computing the mean velocity for the culvert cross section using Manning's equation

$$V = \frac{1.49}{n} R^{2/3} S_o^{1/2}$$

Since the depth of flow is not known the use of tables or charts is recommended in solving this equation (see references). The outlet velocity as computed by this method will usually be high because the normal depth, assumed in using Manning's equation, is seldom reached in the relatively short length of the average culvert. Also, the shape of the outlet channel, including aprons and wingwalls, have much to do with changing the velocity occurring at the end of the culvert barrel. Tailwater is not considered effective in reducing outlet velocities for most inlet control conditions.

In outlet control, the average outlet velocity will be the discharge divided by the cross-sectional area of flow at the outlet. This flow area can be either that corresponding to critical depth, tailwater depth (if below the crown of the culvert) or the full cross section of the culvert barrel.

Performance Curves

Although the procedure given in this circular is primarily for use in selecting a size of culvert to pass a given discharge at a given headwater, a better understanding of culvert operation can be gained by plotting performance curves through some range of discharges and barrel slopes. Such curves can also be used to compare the performance of different sizes and types of culverts. The construction of such curves is described in [Appendix A](#).

Inlets and Culvert Capacity

Inlet shape, edge geometry and skew of the entrance affects culvert capacity. Both the shape and edge geometry have been investigated by recent research but the effect of skew for various flow conditions has not been examined. Results show that the inlet edge geometry is

particularly important to culvert performance in inlet-control flow. A comparison of several types of commonly used inlets can be made by referring to [Chart 2](#) and [Chart 5](#). The type of inlet has some effect on capacity in outlet control but generally the edge geometry is less important than in inlet control. (See [reference 6](#).)

As shown by the inlet control nomograph on [Chart 5](#), the capacity of a thin edge projecting metal pipe can be increased by incorporating the thin edge in a headwall. The capacity of the same thin edged pipe can be further increased if the entrance is rounded, beveled or tapered by the addition of an attachment or the building of these shapes into a headwall. Although research on improving culvert entrances is not complete, sufficient data are available to permit the construction of [Chart 7](#), an inlet control nomograph for the performance of a beveled inlet on a circular culvert. A sketch on the nomograph shows the dimensions of two possible bevels. Although nomographs have not been prepared for other barrel shapes, the capacity of box culverts can be increased at little cost by incorporating a bevel into the headwall. In computing headwater depths for outlet control, when the above bevel is used, k_e equals 0.25 for corrugated metal barrels and 0.2 for concrete barrels.

[Figure 6](#) shows a photograph of a bevel constructed in the headwall of a corrugated metal pipe.

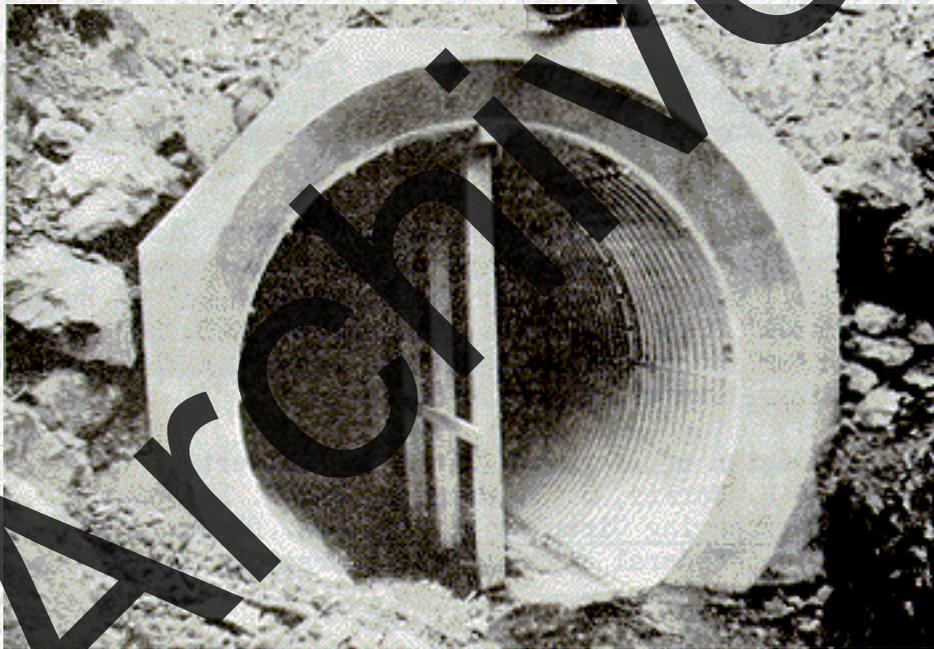


Photo -- Courtesy of Oregon State Highway Department

Figure 6

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Part II : HEC 5

Hydraulic Charts for the Selection of Highway Culverts

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Procedure for Selection of Culvert Size

Step 1: List design data. (See suggested tabulation form, [Figure 7](#).)

- a. Design discharge Q, in cfs., with average return period. (i.e. Q_{25} or Q_{50} etc.)
- b. Approximate length L of culvert, in feet.
- c. Slope of culvert. (If grade is given in percent, convert to slope in ft. per ft.)
- d. Allowable headwater depth, in feet, which is the vertical distance from the culvert invert (flow line) at the entrance to the water surface elevation permissible in the headwater pool or approach channel upstream from the culvert.
- e. Mean and maximum flood velocities in natural stream.
- f. Type of culvert for first trial selection, including barrel material, barrel cross sectional shape and entrance type.

Step 2: Determine the first trial size culvert.

Since the procedure given is one of trial and error, the initial trial size can be determined in several ways:

- a. By arbitrary selection.
- b. By using an approximating equation such as $Q/10 = A$ from which the trial culvert dimensions are determined.
- c. By using inlet control nomographs ([Charts 1-7](#)) for the culvert type selected. If this method is used an $\frac{HW}{D}$ must be assumed, say $\frac{HW}{D} = 1.5$, and using the given Q a trial size is determined.

If any trial size is too large in dimension because of limited height of embankment or availability of size, multiple culverts may be used by dividing the discharge equally between the number of barrels used. Raising the embankment height or the use of pipe arch and box culverts with width greater than height should be considered. Final selection should be based on an economic analysis.

Step 3: Find headwater depth for trial size culvert.

- a. Assuming INLET CONTROL
 1. Using the trial size from step 2, find the headwater depth HW by use of the appropriate inlet control nomograph ([Charts 1-7](#)). Tailwater TW conditions are to be neglected in this determination. HW in this case is found by multiplying $\frac{HW}{D}$ obtained from the nomographs by the height of culvert D.
 2. If HW is greater or less than allowable, try another trial size until HW is acceptable for inlet control before computing HW for outlet control.
- b. Assuming OUTLET CONTROL
 1. Approximate the depth of tailwater TW, in feet, above the invert at the outlet for the design flood condition in the outlet channel. (See general discussion on tailwater, [Part I](#).)

2. For tailwater TW elevation equal to or greater than the top of the culvert at the outlet set h_o equal to TW and find HW by the following equation (Equation 3)

$$HW = H + h_o - LS_o$$

where

HW = vertical distance in feet from culvert invert (flow line) at entrance to the pool surface.

H = head loss in feet as determined from the appropriate nomograph (Charts 8-14)

h_o = vertical distance in feet from culvert invert at outlet to the hydraulic grade line (In this case h_o equals TW, measured in feet above the culvert invert.)

S_o = slope of barrel in ft./ft.

L = culvert length in ft.

3. For tailwater TW elevations less than the top of the culvert at the outlet, find headwater HW by Equation 3 as in b(2) above except that

$$h_o = \frac{d_c + D}{2} \text{ or TW, whichever is the greater.}$$

where

d_c = critical depth in ft. (Charts 15 through 20) Note: d_c cannot exceed D

D = height of culvert opening in ft.

Note: Headwater depth determined in b(3) becomes increasingly less accurate as the headwater computed by this method falls below the value $D + (1 + k_e) \frac{V^2}{2g}$.

(See discussion under "Culvert Flowing Full with Outlet Control", Part II.)

- c. Compare the headwaters found in Step 3(a) and Step 3(b) (Inlet Control and Outlet Control). The higher headwater governs and indicates the flow control existing under the given conditions for the trial size selected.
- d. If outlet control governs and the HW is higher than is acceptable, select a larger trial size and find HW as instructed under Step 3b. (Inlet control need not be checked, since the smaller size was satisfactory for this control as determined under Step 3a.)

Step 4: Try a culvert of another type or shape and determine size and HW by the above procedure.

Step 5: Compute outlet velocities for size and types to be considered in selection and determine need for channel protection.

1. If outlet control governs in Step 3c above, outlet velocity equals $\frac{Q}{A_o}$, where A_o is the cross-sectional area of flow in the culvert barrel at the outlet. If d_c or TW is less than the height of the culvert barrel use A_o corresponding to d_c or TW depth, whichever gives the greater area of flow. A_o should not exceed the total cross-sectional area A of the culvert barrel.
- b. If inlet control governs in Step 3c, outlet velocity can be assumed to equal mean velocity in open-channel flow in the barrel as computed by Manning's equation for the rate of flow, barrel size, roughness and slope of culvert selected.

Note: Charts and tables are helpful in computing outlet velocities. (See [references](#).)

Step 6: Record final selection of culvert with size, type, required headwater, outlet velocity, and economic justification.

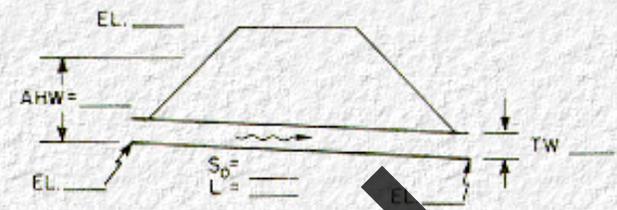
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			DATE: _____													
HYDROLOGIC AND CHANNEL INFORMATION			SKETCH													
$Q_1 =$ _____ $TW_1 =$ _____ $Q_2 =$ _____ $TW_2 =$ _____ ($Q_1 =$ DESIGN DISCHARGE, SAY Q_{25} $Q_2 =$ CHECK DISCHARGE, SAY Q_{50} OR Q_{100})			STATION: _____ 													
			MEAN STREAM VELOCITY = _____ MAX. STREAM VELOCITY = _____													
CULVERT DESCRIPTION (ENTRANCE TYPE)	Q	SIZE	HEADWATER COMPUTATION										CONTROLLING HW	OUTLET VELOCITY	COST	COMMENTS
			INLET CONT.		OUTLET CONTROL				HW = H + h ₀ - LS ₀							
			$\frac{HW}{D}$	HW	K _e	H	d _c	$\frac{d_c + D}{2}$	TW	h ₀	LS ₀	HW				
SUMMARY & RECOMMENDATIONS:																

Figure 7

Inlet-Control Nomographs ([Charts 1 through 7](#))

Instructions for Use

1. To determine headwater (HW), given Q, and size and type of culvert.

Connect with a straightedge the given culvert diameter or height (D) and the discharge Q, or $\frac{Q}{B}$ for box culverts; mark intersection of straightedge on $\frac{HW}{D}$ scale marked (1).

2. If $\frac{HW}{D}$ scale marked (1) represents entrance type used, read $\frac{HW}{D}$ on scale (1). If another of the three entrance types listed on the nomograph is used, extend the point of intersection in (a) horizontally to scale (2) or (3) and read $\frac{HW}{D}$.

3. Compute HW by multiplying $\frac{HW}{D}$ by D.

2. To determine discharge (Q) per barrel, given HW, and size and type of culvert.

a. Compute $\frac{HW}{D}$ for given conditions.

b. Locate $\frac{HW}{D}$ on scale for appropriate entrance type. If scale (2) or (3) is used, extend $\frac{HW}{D}$ point horizontally to scale (1).

c. Connect point on $\frac{HW}{D}$ scale (1) as found in (b) above and the size of culvert on the left scale. Read Q or $\frac{Q}{B}$ on the discharge scale.

d. If $\frac{Q}{B}$ is read in (c) multiply by B (span of box culvert) to find Q.

3. To determine culvert size, given Q, allowable HW and type of culvert.

a. Using a trial size, compute $\frac{HW}{D}$.

b. Locate $\frac{HW}{D}$ on scale for appropriate entrance type. If scale (2) or (3) is used, extend $\frac{HW}{D}$ point horizontally to scale (1).

c. Connect point on $\frac{HW}{D}$ scale (1) as found in (b) above to given discharge and read diameter, height or size of culvert required for $\frac{HW}{D}$ value.

d. If D is not that originally assumed, repeat procedure with a new D.

- [Chart 1. Headwater Depth for Box Culverts with Inlet Control](#)
- [Chart 2. Headwater Depth for Concrete Pipe Culverts with Inlet Control](#)
- [Chart 3. Headwater Depth for Oval Concrete Pipe Culverts Long Axis Horizontal with Inlet Control](#)
- [Chart 4. Headwater Depth for Oval Concrete Pipe Culverts Long Axis Vertical with Inlet Control](#)
- [Chart 5. Headwater Depth for C.M. Pipe Culverts with Inlet Control.](#)
- [Chart 6. Headwater Depth for C.M. Pipe-Arch Culverts with Inlet Control.](#)
- [Chart 7. Headwater Depth for Circular Pipe Culverts with Beveled Ring Inlet Control.](#)

[Go to Part III](#)



Part III : HEC 5

Hydraulic Charts for the Selection of Highway Culverts

[Go to Appendix A](#)

Outlet-Control Nomographs ([Charts 8 through 14](#))

Instructions for Use

Outlet control nomographs solve [Equation 2](#), for head H when the culvert barrel flows full for its entire length. They are also used to determine head H for some part-full flow conditions with outlet control. These nomographs do not give a complete solution for finding headwater HW , since they only give H in [Equation 3](#), $HW = H + h_o - LS_o$. (See discussion for "Culverts Flowing with Outlet Control", [Part I](#).)

1. To determine head H for a given culvert and discharge Q .
 - . Locate appropriate nomograph for type of culvert selected. Find k_e for entrance type in [Appendix B. Table 1](#).
- b. Begin nomograph solution by locating starting point on length scale. To locate the proper starting point on the length scales follow instructions below:
 1. If the n value of the nomograph corresponds to that of the culvert being used, select the length curve for the proper k_e and locate the starting point at the given culvert length. If a k_e curve is not shown for the selected k_e , see (2) below. If the n value for the culvert selected differs from that of the nomograph, see (3) below.
 2. For the n of the nomograph and a k_e intermediate between the scales given, connect the given length on adjacent scales by a straight line and select a point on this line spaced between the two chart scales in proportion to the k_e values.
 3. For a different roughness coefficient n_1 than that of the chart n , use the length scales shown with an adjusted length L_1 , calculated by the formula

$$L_1 = L \left[\frac{n_1}{n} \right]^2 \quad \text{See instruction 2 for } n \text{ values.}$$

- c. Using a straightedge, connect point on length scale to size of culvert barrel and mark the point of crossing on the "turning line". See instruction 3 below for size considerations for rectangular box culvert.

- d. Pivot the straightedge on this point on the turning line and connect given discharge rate. Read head in feet on the head (H) scale. For values beyond the limit of the chart scales, find H by solving [Equation 2](#).

2. Values of n for commonly used culvert materials.

	<u>Concrete</u>		
	Pipe	Boxes	
	0.012	0.012	
	<u>Corrugated Metal</u>		
	Small Corrugations (2 2/3" x 1/2")	Medium Corrugations (3" x 1")	Large Corrugations (6" x 2")
Unpaved	0.024	0.027	Varies*
25% paved	0.021	0.023	0.026
Fully Paved	0.012	0.012	0.012

*Variation in n with diameter shown on charts. The various n values have been incorporated into the nomographs and no adjustments for culvert length is required as instructed in lb(3).

3. To use the box culvert nomograph, [Chart 8](#), for full-flow for other than square boxes.
- Compute cross-sectional area of the rectangular box.
 - Connect proper point (see instruction 1) on length scale to barrel area³ and mark point on turning line.
 - Pivot the straightedge on this point on the turning line and connect given discharge rate. Read head in feet on the head (H) scale.

[Chart 8. Head for Concrete Box Culverts Flowing Full, n=0.012](#)

[Chart 9. Head for Concrete Pipe Culverts Flowing Full, n=0.012](#)

[Chart 10. Head for Oval Concrete Pipe Culverts, Long Axis Horizontal or Vertical Flowing Full, n=0.012](#)

[Chart 11. Head for Standard C.M. Pipe Culverts Flowing Full, n=0.024](#)

[Chart 12. Head for Standard C.M. Pipe-Arch Culverts Flowing Full, n=0.024](#)

[Chart 13. Head for Structural Plate, Corrugated Metal Pipe Culverts Flowing Full, n=0.0328 to 0.0302](#)

[Chart 14. Head for Structural Plate, Corrugated Metal Pipe Arch Culverts, 18 in. Corner Radius, Flowing Full, n=0.0327 to 0.0306](#)

[Chart 15. Critical Depth, Rectangular Section](#)

[Chart 16. Critical Depth, Circular Pipe](#)

[Chart 17. Critical Depth, Oval Concrete Pipe, Long Axis Horizontal](#)

[Chart 18. Critical Depth, Oval Concrete Pipe, Long Axis Vertical](#)

[Chart 19. Critical Depth, Standard C.M. Pipe-Arch](#)

[Chart 20. Critical Depth, Structural Plate, C.M. Pipe-Arch](#)

NOTE:³The area scale on the nomograph is calculated for barrel cross-sections with span B twice the height D ; its close correspondence with area of square boxes assures it may be used for all sections intermediate between square and $B = 2D$ or $B = 1/2D$ For other box proportions use [Equation 2](#) for more accurate results.

[Go to Appendix A](#)

Archived



Appendix A : HEC 5

Performance Curves

[Go to Appendix B](#)

The principal disadvantage in using nomographs for the selection of culvert sizes is that it requires the trial and error solution described in this circular. Some engineers who limit their selection to a relatively small number of types of culverts would find it advantageous to prepare performance curves such as shown in [Figure 8](#). These curves are applicable through a range of headwaters and discharges for a length and type of culvert. Usually charts with length intervals of 25 to 50 feet are satisfactory for design purposes.

[Figure 8](#) is plotted from the data shown in the following tabulations. These data were obtained from the nomographs contained in this circular. (Computer programs are available from Public Roads for making these computations.) The first tabulation is for the inlet-control curve on [Figure 8](#), and the second tabulation is for the outlet control curves.

Data for Inlet-Control Curve

$\frac{HW^*}{D}$ (Assume)	Q* (Read)	$\frac{HW}{D} \times 4$
.5	21c.f.s.	2.0ft.
.6	29	2.4
.7	37	2.8
.8	46	3.2
.9	56	3.6
1.0	65	4.0
1.1	74	4.4
1.3	90	5.2
1.5	102	6.0
1.7	112	6.8
2.0	126	8.0
2.5	145	10.0
3.0	165	12.0

*From [Chart 5](#) Projecting Inlet (3)

Data for Outlet-Control Curves

Q	d_c	$\frac{d_c + D}{2}$	H	HW for Various S_o				
(Assume)	Chart 16	(Compute)	Chart 11	0%	.5%	1%	1.5%	2.0%

20 cfs	1.3 ft.	2.6 ft.	.2* ft.	2.8ft.	-	-	-	-
40	1.9	3.0	.8	3.8	2.8	1.8	.8	-
60	2.3	3.2	1.9	5.1	4.1	3.1	2.1	1.1
80	2.7	3.4	3.3	6.7	5.7	4.7	3.7	2.7
100	3.1	3.6	5.2	8.8	7.8	6.8	5.8	4.8
120	3.3	3.6	7.5	11.1	10.1	9.1	8.1	7.1
140	3.5	3.8	10.2	14.0	13.0	12.0	11.0	10.0
160	3.7	3.8	13.6	17.4	16.4	15.4	14.4	13.4

$$HW = H + h_o - LS_o \quad \text{where } h_o = \frac{d_c + D}{2}$$

*From [Chart 11](#) - or by [Equation 2](#).

The curves plotted apply only to the type and length of culvert shown. Culverts placed on grades steeper than about 2.5 percent will operate on the inlet control curve for the headwater-discharge range of this plot. If a free outfall condition does not exist a correction for tailwater should be made as instructed in Step 3b, Part II of "Procedure for Selection of Culvert Size".

Archived

HYDRAULIC PERFORMANCE CURVES 48-INCH C.M. PIPE CULVERT WITH PROJECTING INLET

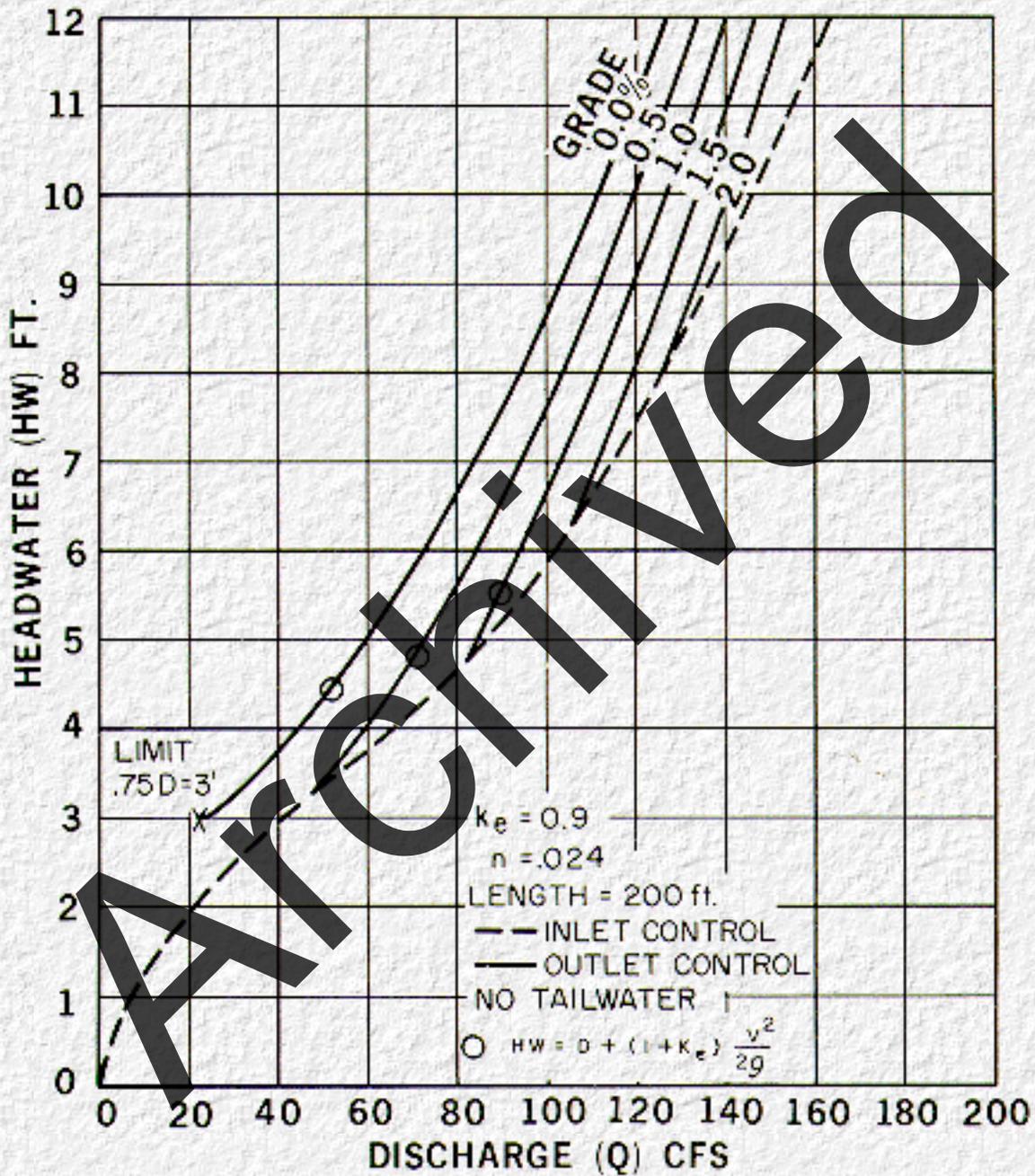


Figure 8. Hydraulic Performance Curves, 48-Inch C.M. Pipe Culvert with Projecting Inlet

[Go to Appendix B](#)



Appendix B : HEC 5

Hydraulic Charts for the Selection of Highway Culverts

[Go to Appendix C](#)

Table 1. Entrance Loss Coefficients

Outlet Control, Full or Partly Full	
Entrance head loss $H_e = k_e \frac{v^2}{2g}$	
Type of Structure and Design of Entrance	Coefficient k_e
Pipe, Concrete	
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove-end)	0.2
Square-edge	0.5
Rounded (radius = 1/12D)	0.2
Mitered to conform to fill slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7° or 45° bevels	0.2
Side-or slope-tapered inlet	0.2
Pipe, or Pipe-Arch Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge. .	0.5
Mitered to conform to fill slope, paved or unpaved slope	0.7
*End-Section conforming to fill slope.	0.5
Beveled edges, 33.7° or 45° bevels.	0.2
Side-or slope-tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrel dimension, or beveled edges on 3 sides . .	0.2
Wingwalls at 30° to 75° to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of 1/12 barrel dimension, or beveled top edge	0.2
Wingwall at 10° to 25° to barrel	
Square-edged at crown	0.5

Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side-or slope-tapered inlet	0.2

*Note: "End Section conforming to fill slope," made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control. Some end sections, incorporating a closed taper in their design have a superior hydraulic performance. These latter sections can be designed using the information given for the beveled inlet, [Part I](#).

Table 2. Manning's n for Natural Stream Channels⁴
(Surface width at flood stage less than 100 ft.)

1. Fairly regular section:	
. Some grass and weeds, little or no brush	0.030--0.035
b. Dense growth of weeds, depth of flow materially greater than weed height	0.035--0.05
c. Some weeds, light brush on banks	0.035-0.05
d. Some weeds, heavy brush on banks	0.05-0.07
e. Some weeds, dense willows on banks	0.06 -0.08
f. For trees within channel, with branches submerged at high stage, increase all above values by	0.01-0.02
2. Irregular sections, with pools, slight channel meander; <u>increase</u> values given above about	0.01 --0.02
3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage:	
. Bottom of gravel, cobbles, and few boulders	0.04--0.05
2. Bottom of cobbles, with large boulders	0.05--0.07

⁴From "Design Charts for Open Channel Flow", (see [references](#)).

[Go to Appendix C](#)



Appendix C : HEC 5

Illustrative Problems

[Go to Table of Contents](#)

PROJECT: I-46 (1) DESIGNER: J.A.F.
 DATE: 2-18-64

HYDROLOGIC AND CHANNEL INFORMATION

$Q_1 = \frac{180 \text{ cfs.} = Q_{25}}{TW_1 = \frac{3.5}$
 $Q_2 = \frac{225 \text{ cfs.} = Q_{50}}{TW_2 = \frac{4.0}$

(Q_1 = DESIGN DISCHARGE, SAY Q_{25}
 Q_2 = CHECK DISCHARGE, SAY Q_{50} OR Q_{100})

SKETCH
 STATION: 6+21

EL. 114
 AHW = 10'
 EL. 100
 $S_0 = \frac{0.25\%}{L = 200}$
 EL. 20'
 TW 3.5'
 MEAN STREAM VELOCITY = $\frac{10}{\text{sec}}$
 MAX. STREAM VELOCITY = $\frac{18}{\text{sec}}$

CULVERT DESCRIPTION (ENTRANCE TYPE)	D	SIZE	HEADWATER COMPUTATION										CONTROLLING HW	OUTLET VELOCITY	COST	COMMENTS	
			INLET CONT.		OUTLET CONTROL $HW = h_0 + h_c - LS_0$												
			$\frac{HW}{D}$	HW	K_e	H	d_c	$\frac{d_c D}{2}$	TW	h_0	LS_0	HW					
CIRCULAR CMP PROJ. ENT.	180		Assume 1.5	7.5	0.60	9.7	3.9	4.2	3.5	4.2	10.0	3.9	9.9	16.5			
"	180	54"	2.2	9.9	.9	9.7	3.9	4.2	3.5	4.2	10.0	3.9	9.9	16.5			
"	225	54"	3.15	14.2	.9	15.3	4.2	4.4	4.0	4.4	10.0	3.9	14.2	17.0			HW high for Q_{50} - Try 60"
"	180	60"	1.51	7.55	.9	9.7	3.9	4.4	3.5	4.4	10.0	0.3	7.55	16.7			
"	225	60"	2.1	10.5	.9	9.7	4.2	4.6	4.0	4.6	10.0	3.9	10.5	17.5			

SUMMARY & RECOMMENDATIONS:
 Velocities read from chart 45-47- "Design charts for open channel flow." (see references). Outlet velocities are about the same for each size, indicating change in size has little effect. Size selected (60 or 54-inch) depends on designer's confidence in flood estimate and damage incurred if a larger flood should occur. Note that TW must be greater than 10.1' for outlet control to govern for the 54" pipe flowing 180 cfs; accurate determination of TW depths is unnecessary in most cases.

PROJECT: 142 B

DESIGNER: L. D. K

DATE: 2-18-64

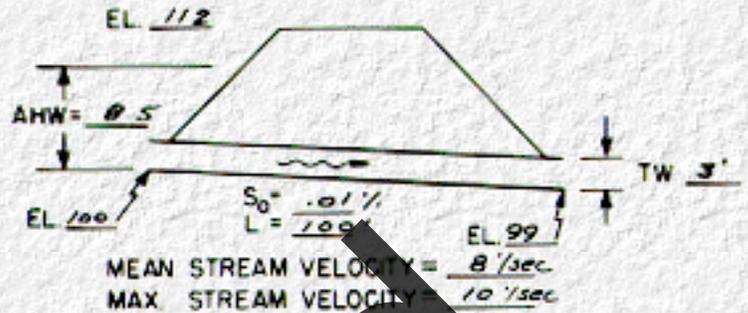
HYDROLOGIC AND CHANNEL INFORMATION

$Q_1 = 160 \text{ cfs} = Q_{50}$ $TW_1 = 5.0'$
 $Q_2 = \underline{\hspace{2cm}}$ $TW_2 = \underline{\hspace{2cm}}$

(Q_1 = DESIGN DISCHARGE, SAY Q_{25}
 Q_2 = CHECK DISCHARGE, SAY Q_{50} OR Q_{100})

SKETCH

STATION: 321+14



HEADWATER COMPUTATION

CULVERT DESCRIPTION (ENTRANCE TYPE)	D	SIZE	HEADWATER COMPUTATION											OUTLET VELOCITY	COMMENTS		
			INLET CONT.		OUTLET CONTROL							HW = H + h ₀ - LS ₀					
			H _W /D	H _W	K _e	H	d _c	$\frac{d_c + D}{2}$	TW	h ₀	LS ₀	HW	H _W				
CMP (C.P.) Headwall	160	54"	1.56	7.0													HW less than 8.5' try 48"
"	160	48"	2.25	9.0	.5	8.3	3.7	3.8	3	3.8	1.0	11.1	11.1	13.2/sec			HW High try 54"
"	160	54"	1.56	7.0	.5	4.7	3.0	4.1	3	4.1	1.0	7.8	7.8	11.1/sec			velocity of d _c size ok.
Concrete (C.P.) Sp. Edge - Hdwl	160	48"	2.35	9.4	.5	4.7	3.7	3.8	3	3.8	1.0	7.5	9.6	10/sec			HW High try 54"
"	160	54"	1.6	7.2	.5	2.9	3.6	4.1	3	4.1	1.0	6.0	7.2	16.7/sec			HW OK vel > 10 mph try 48 9.0 cfs
Concrete (C.P.) Groove end - Hdwl	160	48"	1.95	7.8	.2	4.0	3.7	3.8	3	3.8	1.0	6.8	7.8	14.0/sec			HW OK vel high

SUMMARY & RECOMMENDATIONS:

The selection of a 54" CMP with headwall will keep the headwater below the AWH with a minimum outlet velocity. A 48" concrete pipe with groove edged entrance gives equal HW and slightly higher outlet velocity. Protection of outlet channel might be necessary in some locations.

PROJECT: E 14-2(3)

DESIGNER: F.R.R.

DATE: 2-20-64

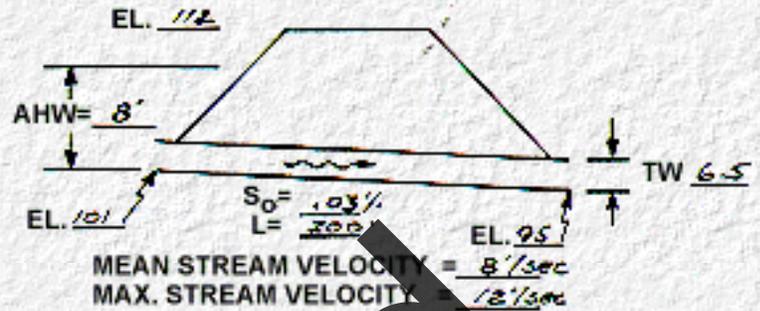
HYDROLOGIC AND CHANNEL INFORMATION

SKETCH

STATION: 8+61

$Q_1 = \underline{400 \text{ cfs. } Q_{50}}$ $TW_1 = \underline{6.5'}$
 $Q_2 = \underline{\hspace{2cm}}$ $TW_2 = \underline{\hspace{2cm}}$

(Q_1 - DESIGN DISCHARGE, SAY Q_{25}
 Q_2 - CHECK DISCHARGE, SAY Q_{50} OR Q_{100})



CULVERT DESCRIPTION (Entrance Type)	Q	SIZE	HEADWATER COMPUTATION										CONTROLLING HW	OUTLET VELOCITY	COST	COMMENTS	
			INLET CONT.		OUTLET CONTROL HW=H+ho-LS _o												
			HW/D	HW	K _e	H	d _c	$\frac{d_c+D}{2}$	TW	h _o	LS _o	HW					
Concrete (C/R) Gr. End Proj	400		Assume 1.5														HW = 9.1 Too high - try 84"
"	400	84"	1.18	8.3													HW High Try 90"
"	400	90"	1.05	7.9	.2	1.9	5.2	6.3	6.5	6.5	6.5	6.0	2.4	7.9	28 ft/sec I.C. 10 ft/sec O.C.		If too large try 2 pipes
Same type 2 pipes	200	54"	1.85	8.3													Too small
"	200	60"	1.38	6.9	.2	3.4	4.0	4.5	6.5	6.5	6.5	6.0	3.9	6.9	23 ft/sec I.C. 10 ft/sec O.C.		Use See comments
Cit. CMP Bevel B (short?)	200	60"	1.34	6.7	.25	4.2	4.0	4.5	6.5	6.5	6.5	6.0	6.7	6.7	14 ft/sec I.C. 10 ft/sec O.C.		Use Bevel A can be used here
			Might try single concrete oval or metal arches														

SUMMARY & RECOMMENDATIONS:

Problem to illustrate use of double pipes if one pipe is too high or not available. Inlet control governs TW submerges outlet for all double barrels. Velocities are computed for both inlet control and for full flow at outlet caused by TW. Two 60-inch concrete pipes or two 60-inch CMP with inlets shown satisfy headwater limitations. Concrete pipe will give considerably higher outlet velocities if tailwater is not effective in causing the culvert to fill at the outlet.

APPROVED

PROJECT: I 85-2

DESIGNER: L. A. H.

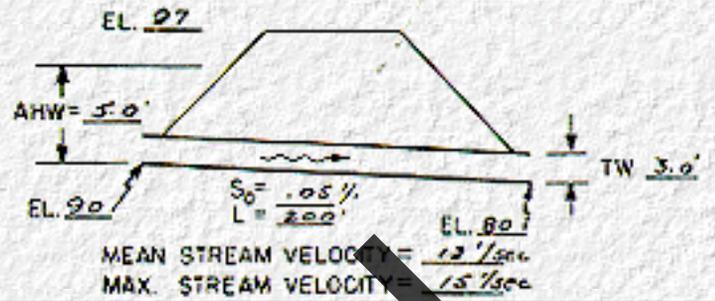
DATE: 2-23-64

HYDROLOGIC AND CHANNEL INFORMATION

$Q_1 = \frac{120 \text{ cfs.}}{Q_{25}}$ $TW_1 = \frac{5.0'}{}$
 $Q_2 = \frac{120 \text{ cfs.}}{Q_{50}}$ $TW_2 = \frac{5.0'}{}$
 (Q_1 - DESIGN DISCHARGE, SAY Q_{25}
 Q_2 - CHECK DISCHARGE, SAY Q_{50} OR Q_{100})

SKETCH

STATION: 316+10



CULVERT DESCRIPTION (ENTRANCE TYPE)	Q	SIZE	HEADWATER COMPUTATION										CONTROLLING HW	OUTLET VELOCITY	COST	COMMENTS	
			INLET CONT.		OUTLET CONTROL						HW = H + h ₀ - LS ₀						
			HW / 0	HW	K _e	H	d _c	$\frac{d_c + D}{2}$	TW	h ₀	LS ₀	HW					
CM Pipe Arch Mitered	120	54"	1.25	5.6'													HW High Try 60"
"	120	60"	.97	4.9	.7	2.5	3.0	6.0	3.0	4.0	10.0	4.9					Need more cover - try arch
CM Arch Mitered	120	72" 64"	1.24	4.6	.7	3.4	2.6	3.0	3.0	5.0	10.0	4.6					check box culvert
Concrete Box 30° w.w.	120	6" 6"	1.23	4.9	.4	2.0	3.1	3.5	3.0	3.5	10.0	4.9					
Concrete Oval Gr. End Proj.	120	60" 38"	1.51	4.8	.2	2.9	2.7	2.9	3.0	3.0	10.0	4.8					
Concrete Cir Greave End Proj	120	54"	1.11	5.0	.2	1.7	3.1	3.8	3.0	3.8	10.0	5.0					

SUMMARY & RECOMMENDATIONS:

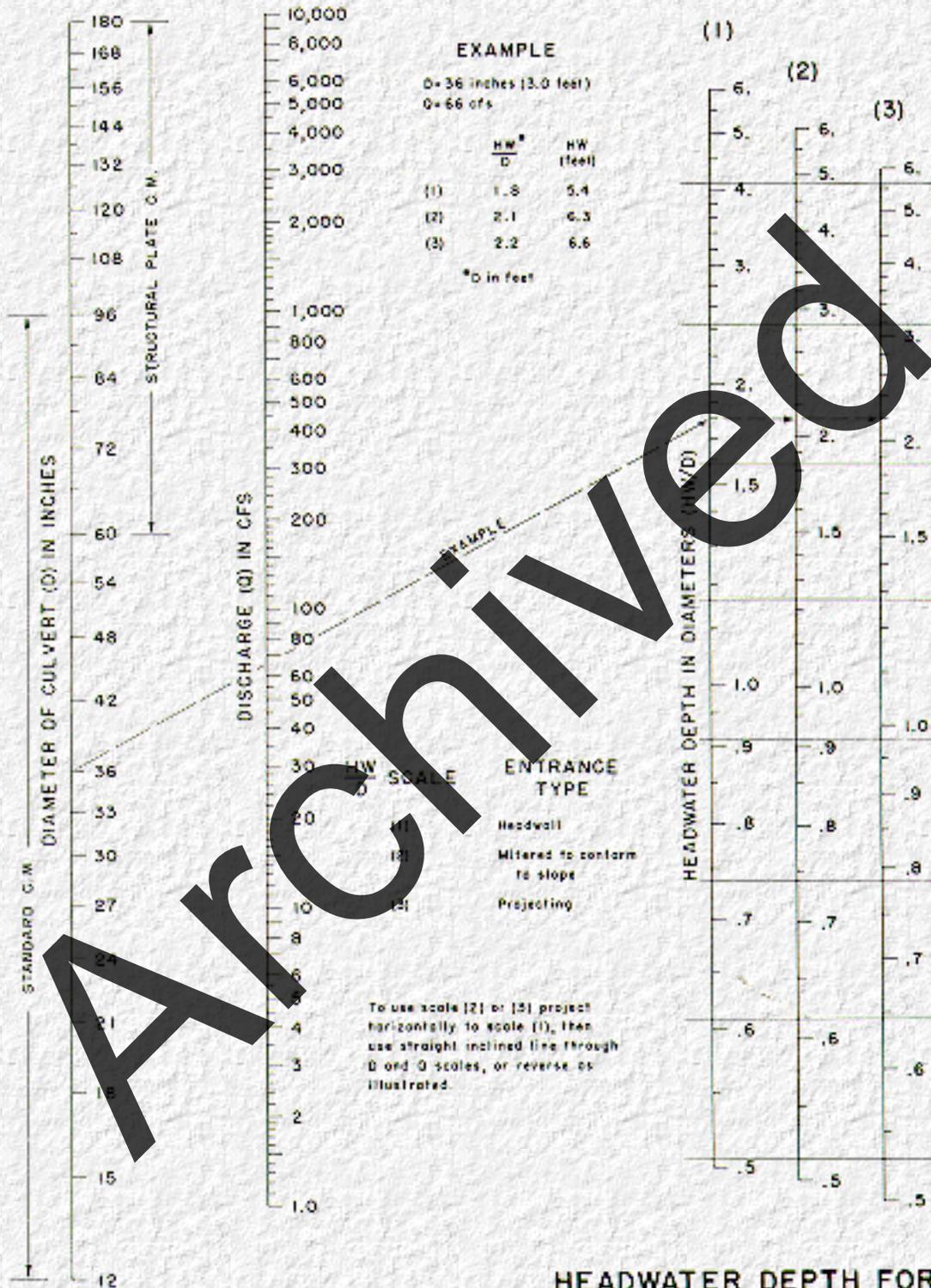
In-place cost, availability, location, cover requirements, etc. should be considered by the designer in selecting culvert. CM pipe arch culverts or concrete oval pipes might be a solution where cover is limited

[Go to Table of Contents](#)

References

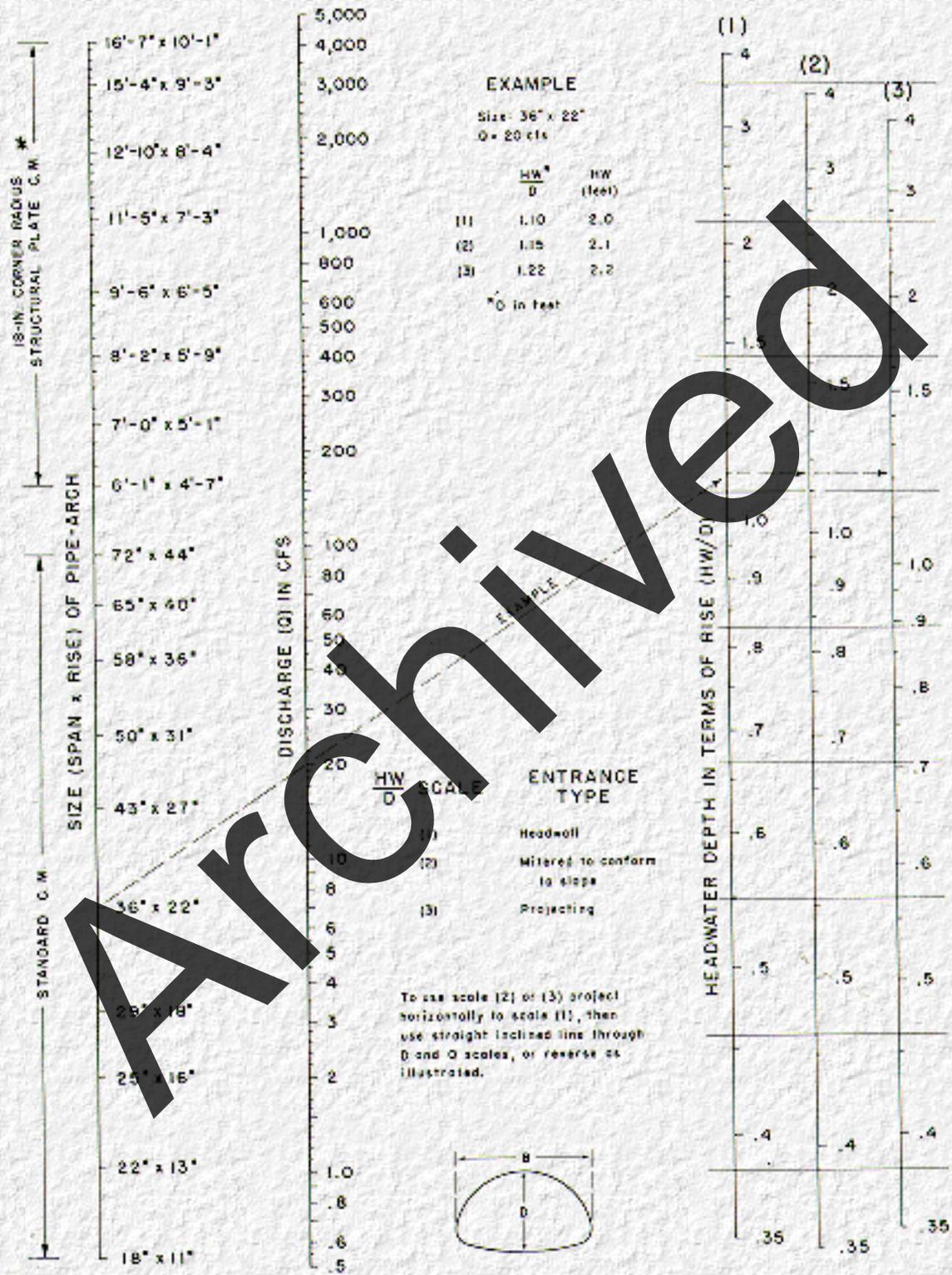
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CHART 5



**HEADWATER DEPTH FOR
C. M. PIPE CULVERTS
WITH INLET CONTROL**

CHART 6

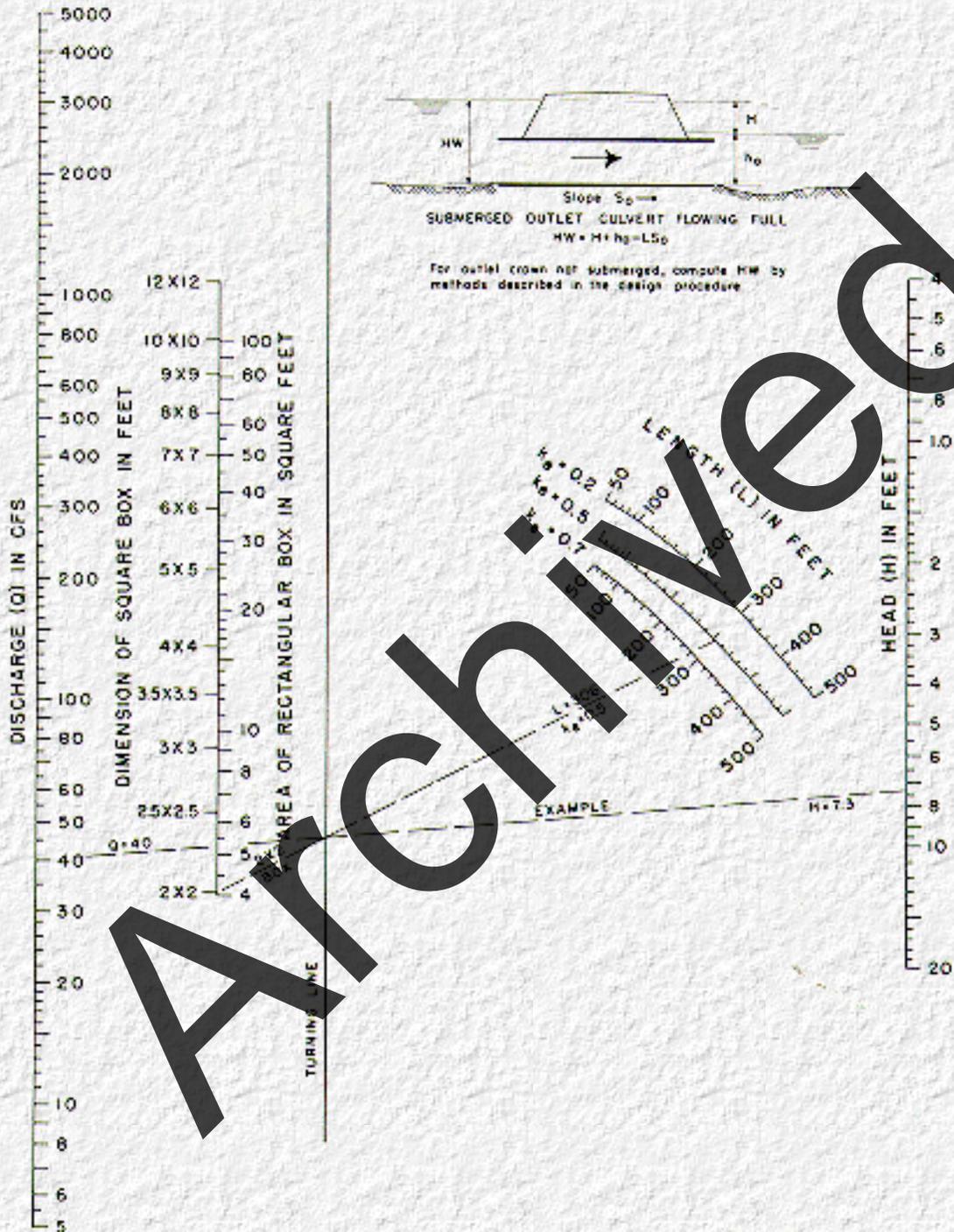


*ADDITIONAL SIZES NOT DIMENSIONED ARE LISTED IN FABRICATOR'S CATALOG

Chart 7



CHART 8



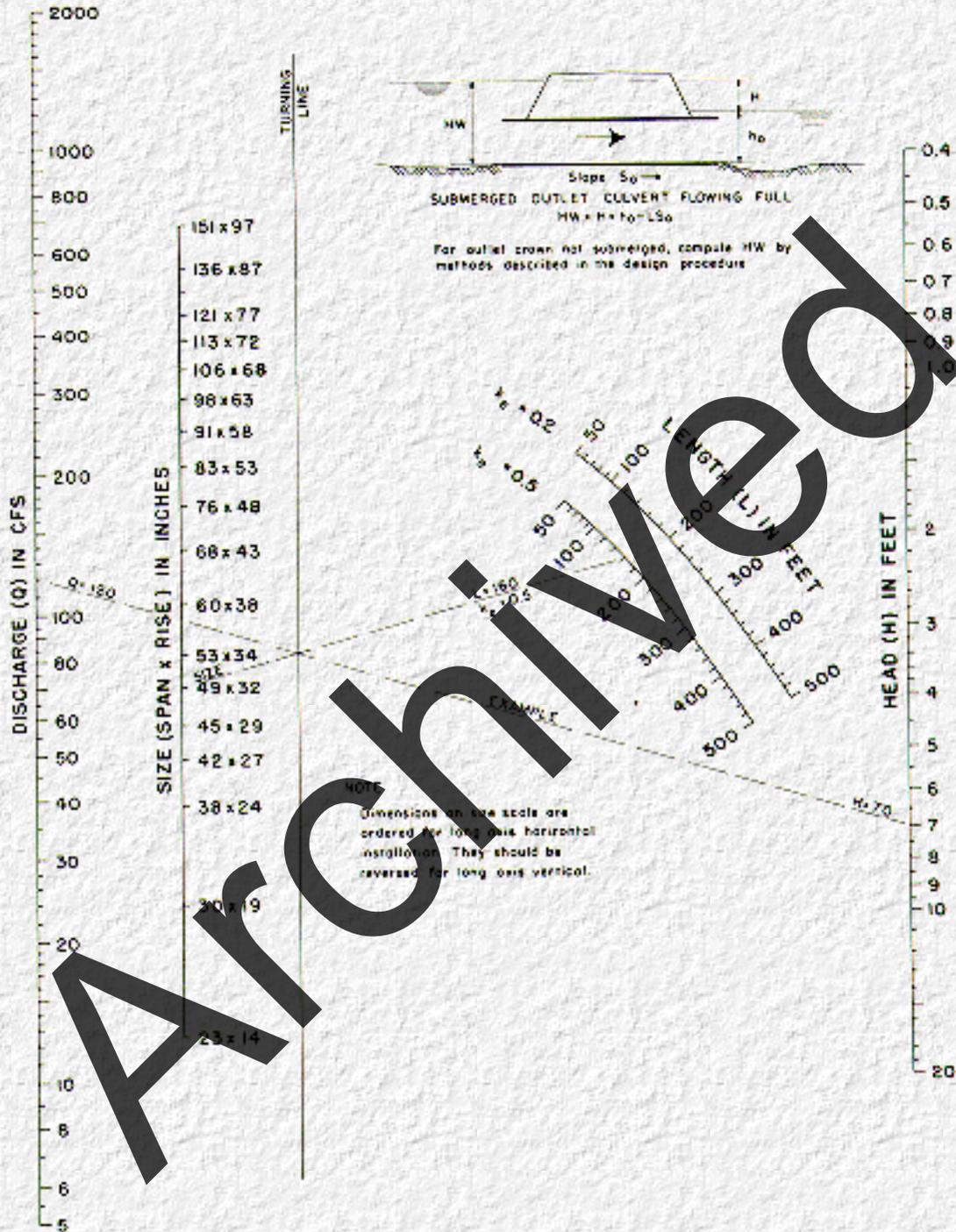
HEAD FOR
 CONCRETE BOX CULVERTS
 FLOWING FULL
 $n = 0.012$

CHART 9



HEAD FOR
CONCRETE PIPE CULVERTS
FLOWING FULL
 $n = 0.012$

CHART 10



HEAD FOR
 OVAL CONCRETE PIPE CULVERTS
 LONG AXIS HORIZONTAL OR VERTICAL
 FLOWING FULL
 $n = 0.012$

CHART II

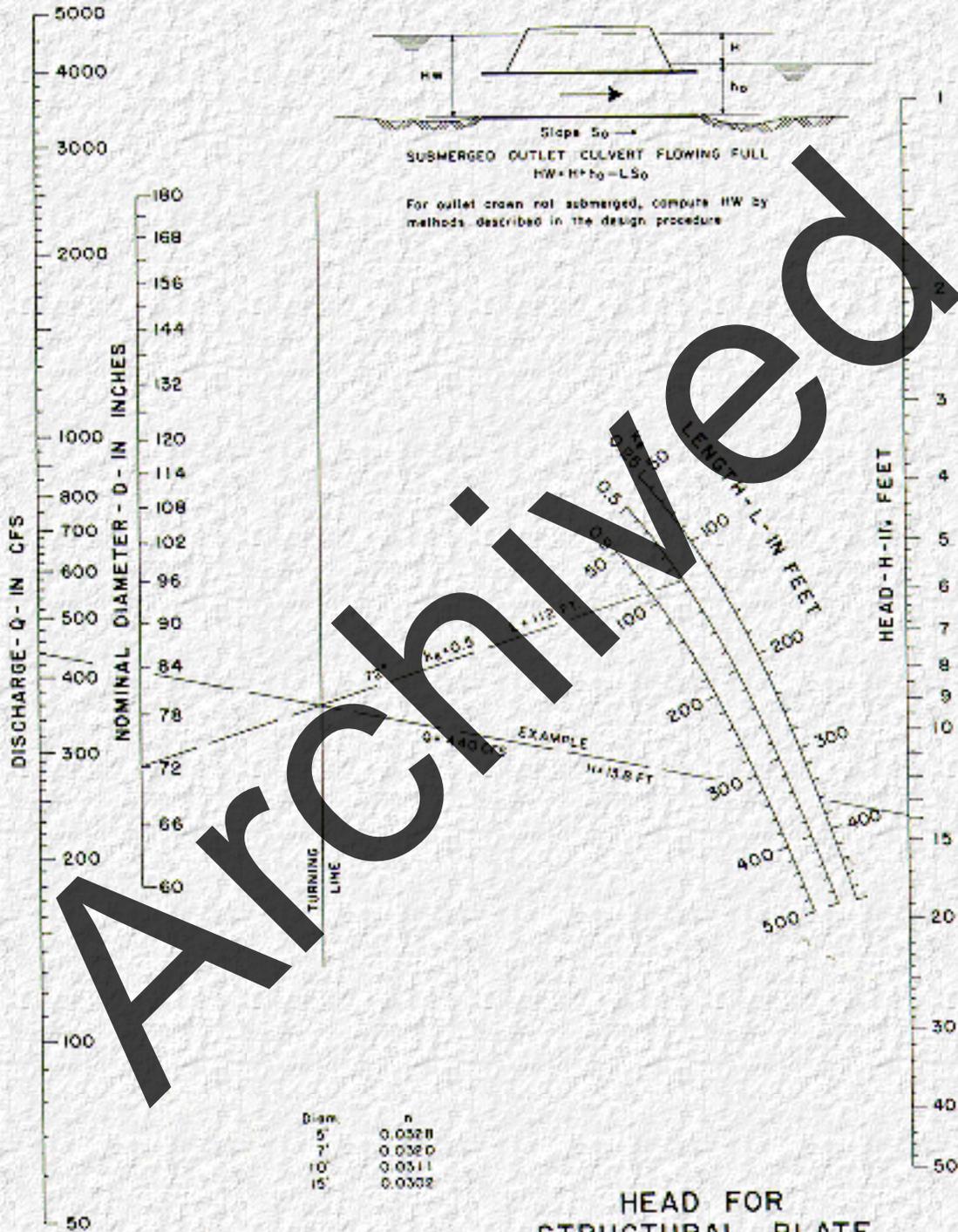


CHART 12



HEAD FOR
 STANDARD C. M. PIPE-ARCH CULVERTS
 FLOWING FULL
 $n=0.024$

CHART 13



HEAD FOR
STRUCTURAL PLATE
CORR. METAL PIPE CULVERTS
FLOWING FULL
n = 0.0328 TO 0.0302

CHART 14

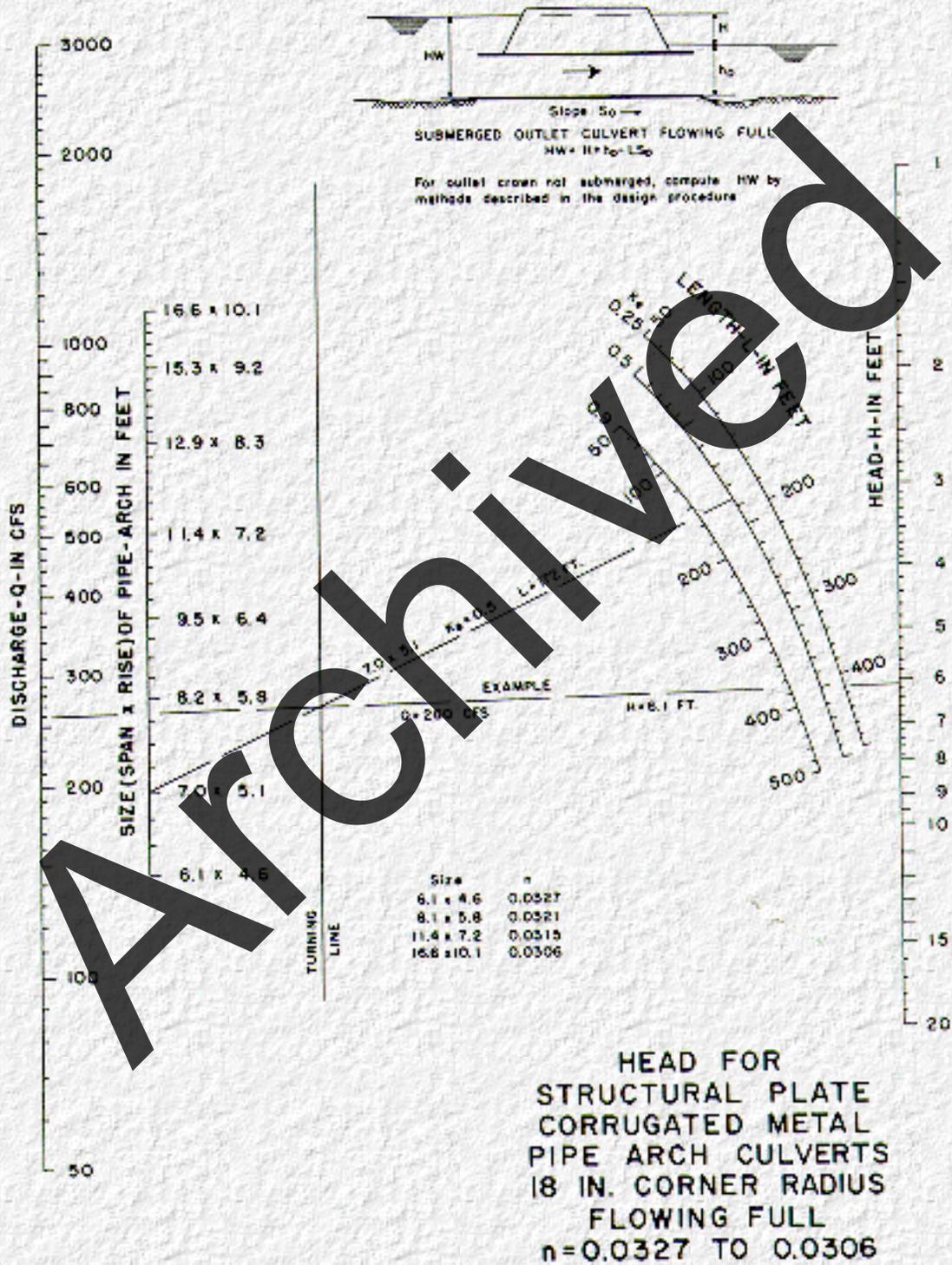


Chart 15

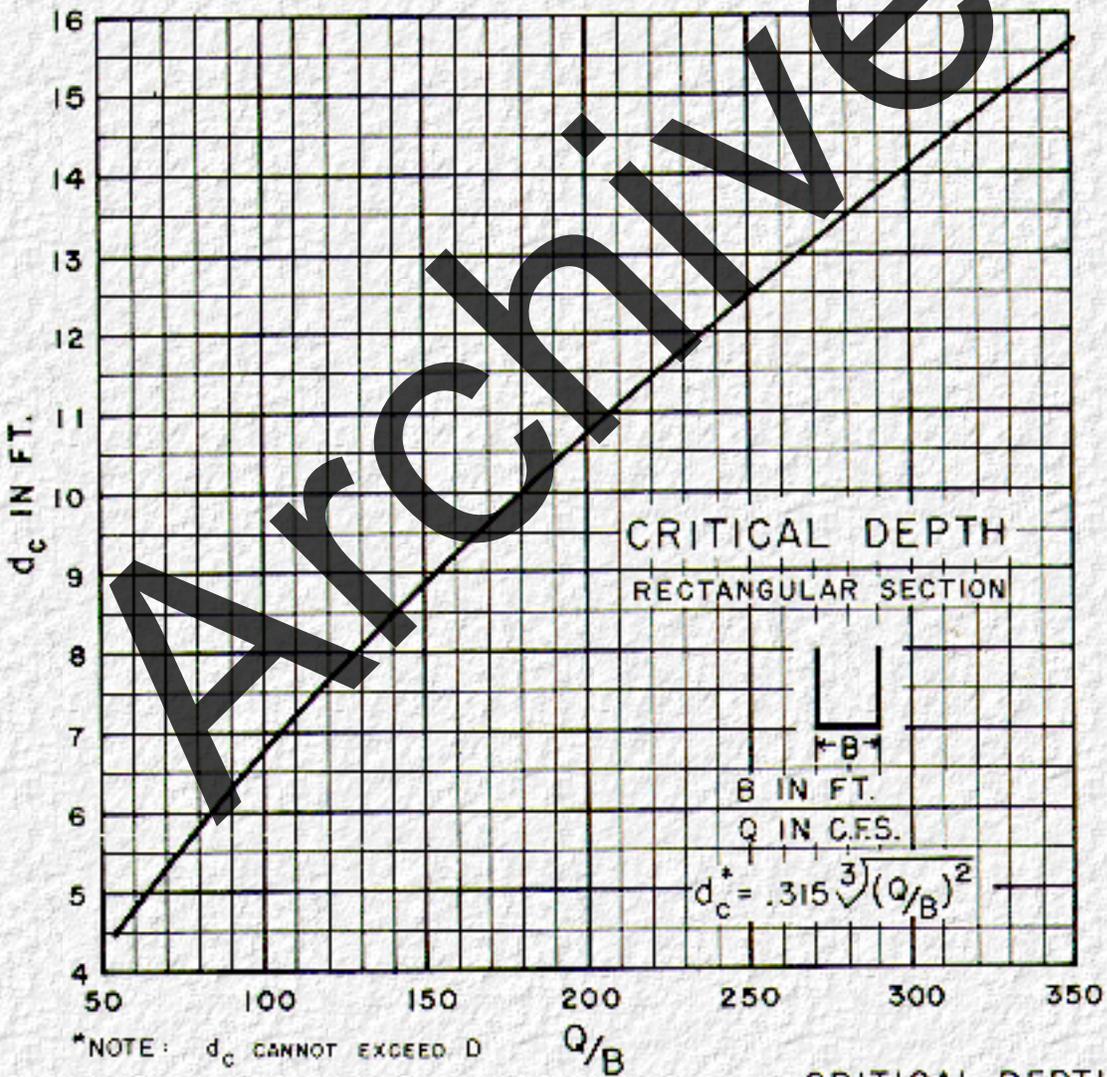
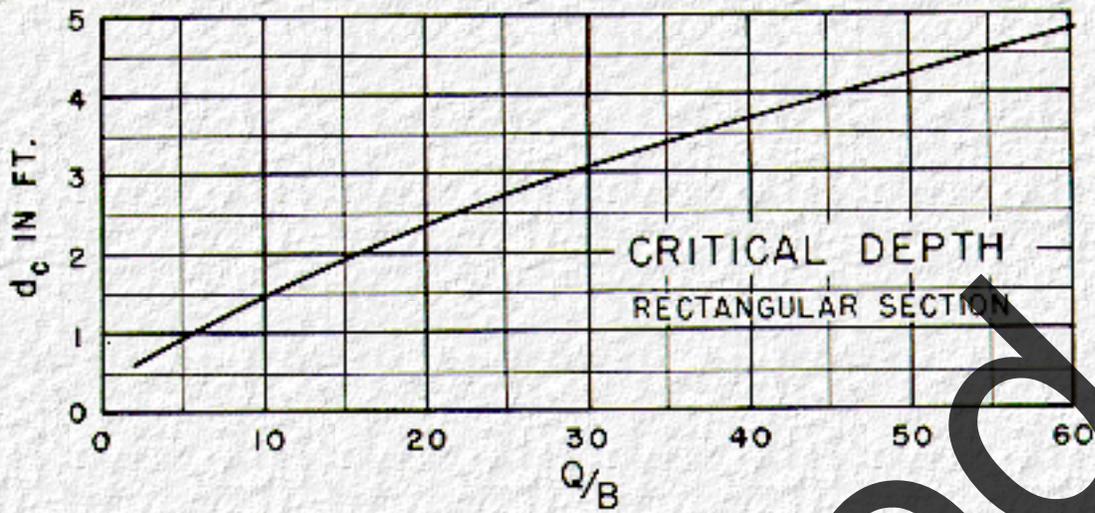


CHART 16

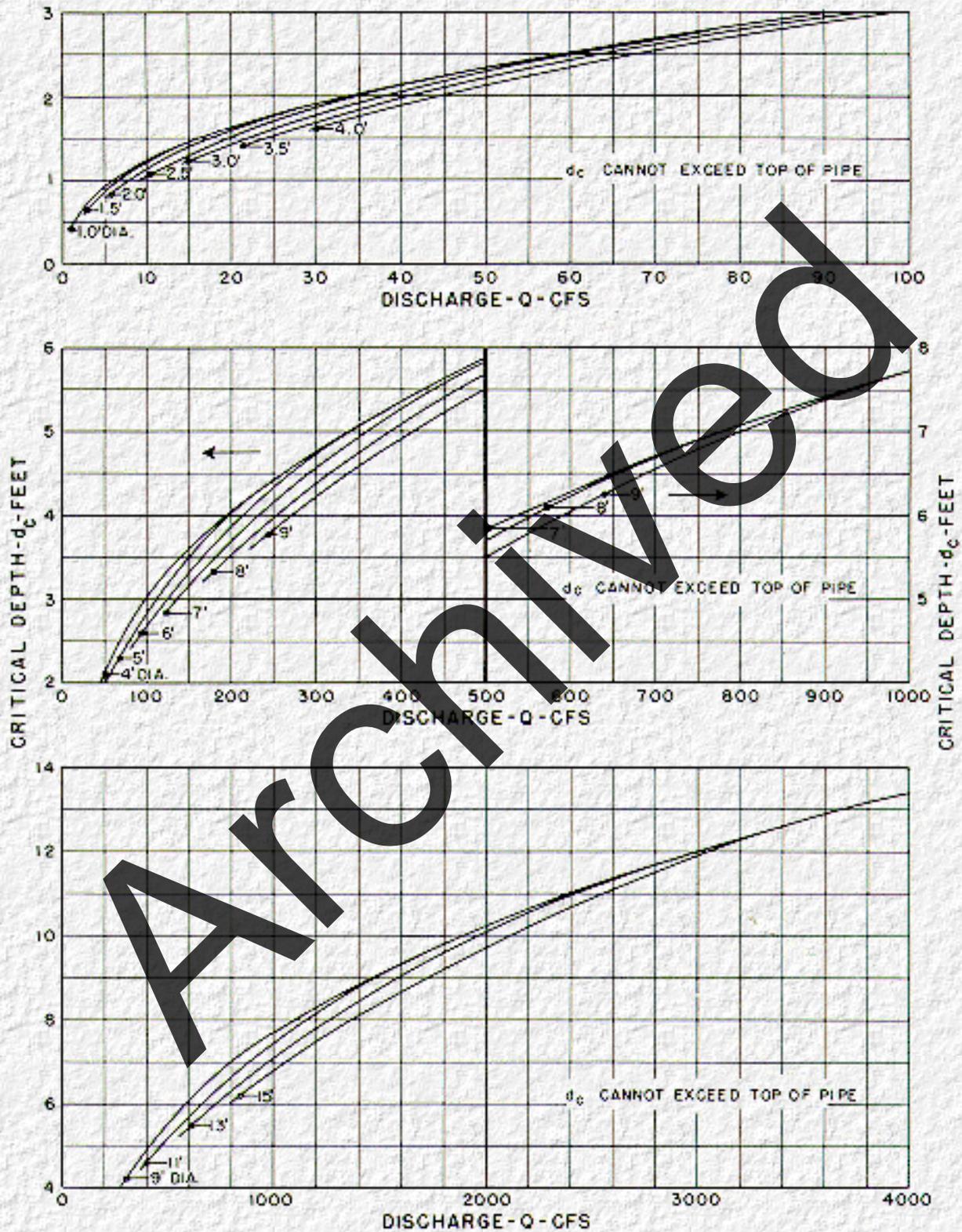
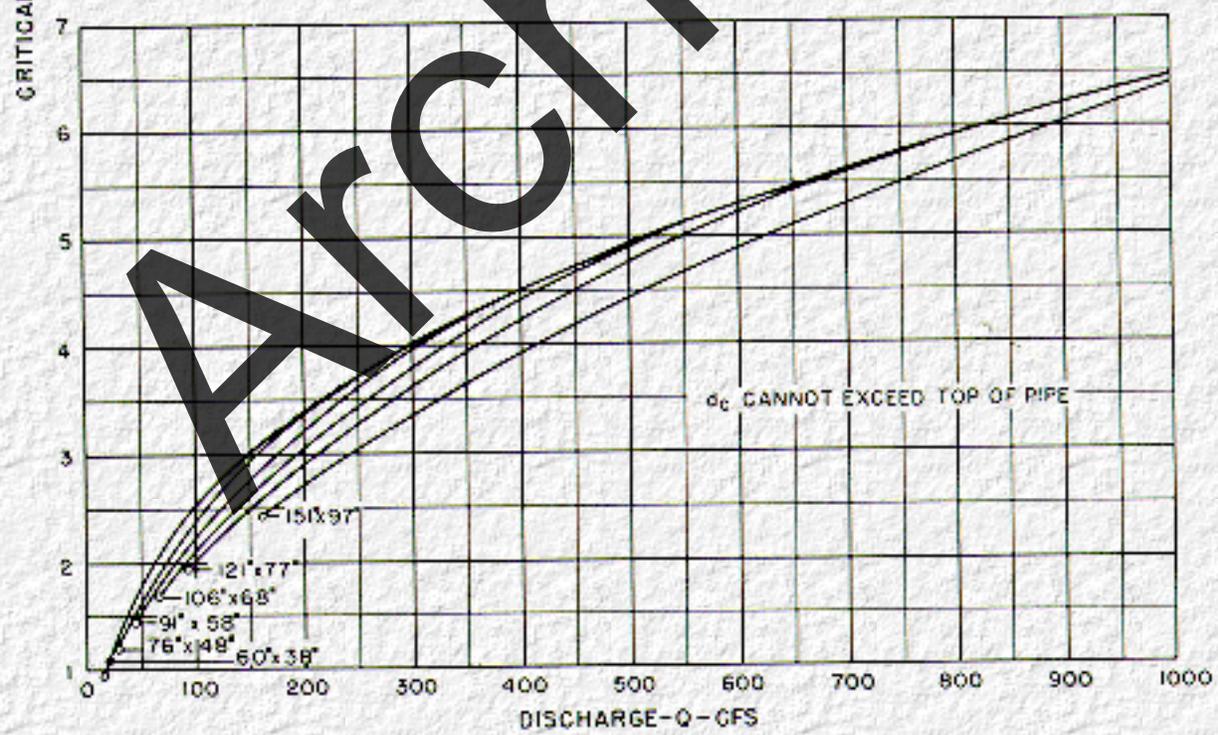
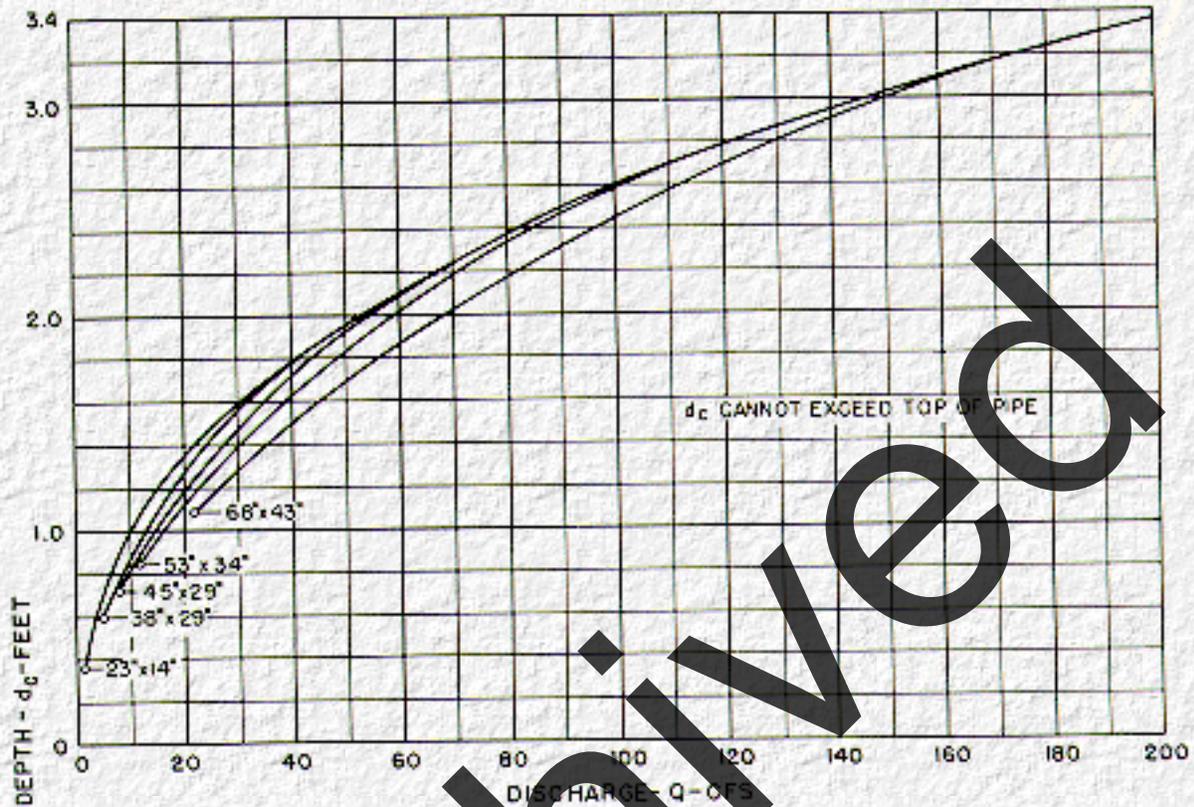


CHART 17



BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS HORIZONTAL

CHART 18

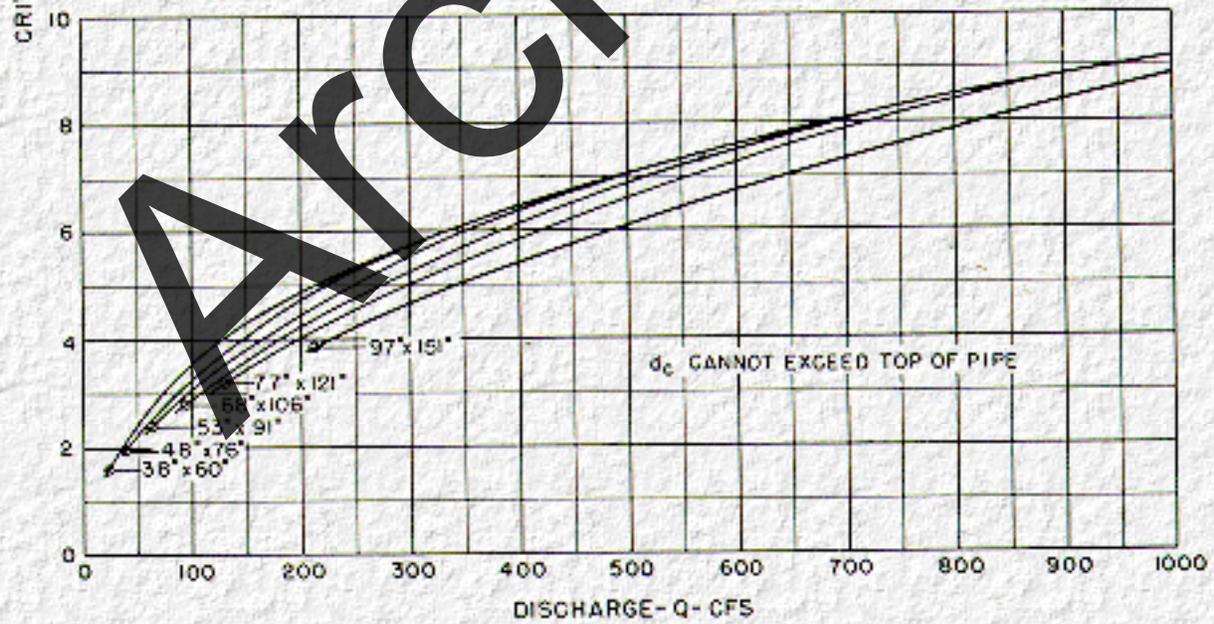
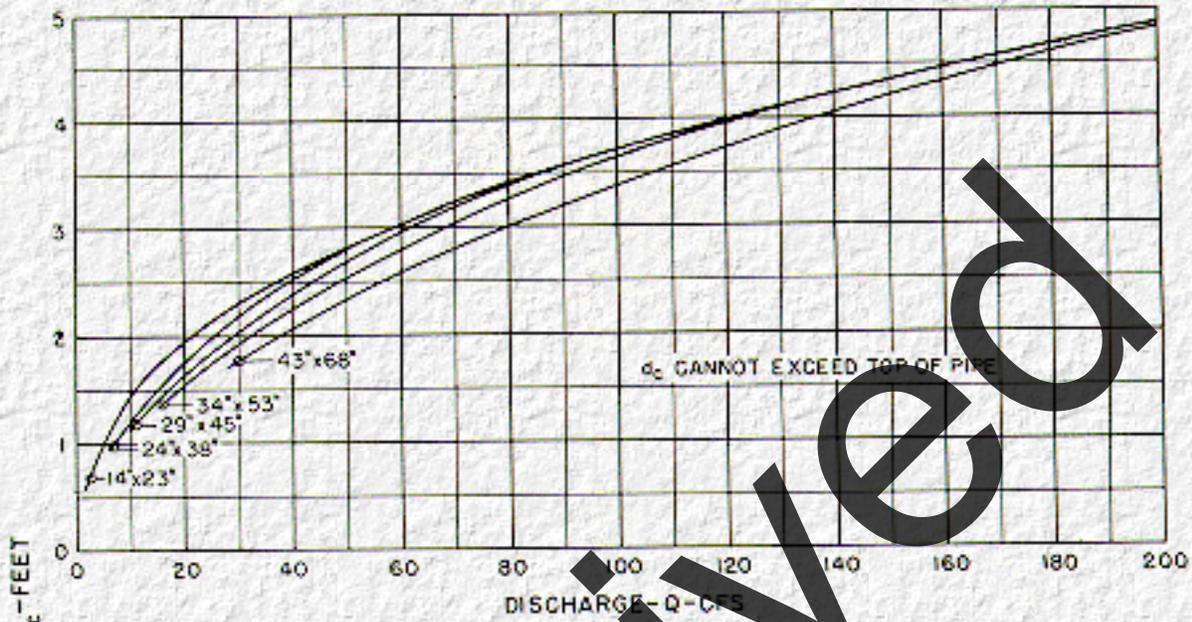


CHART 19

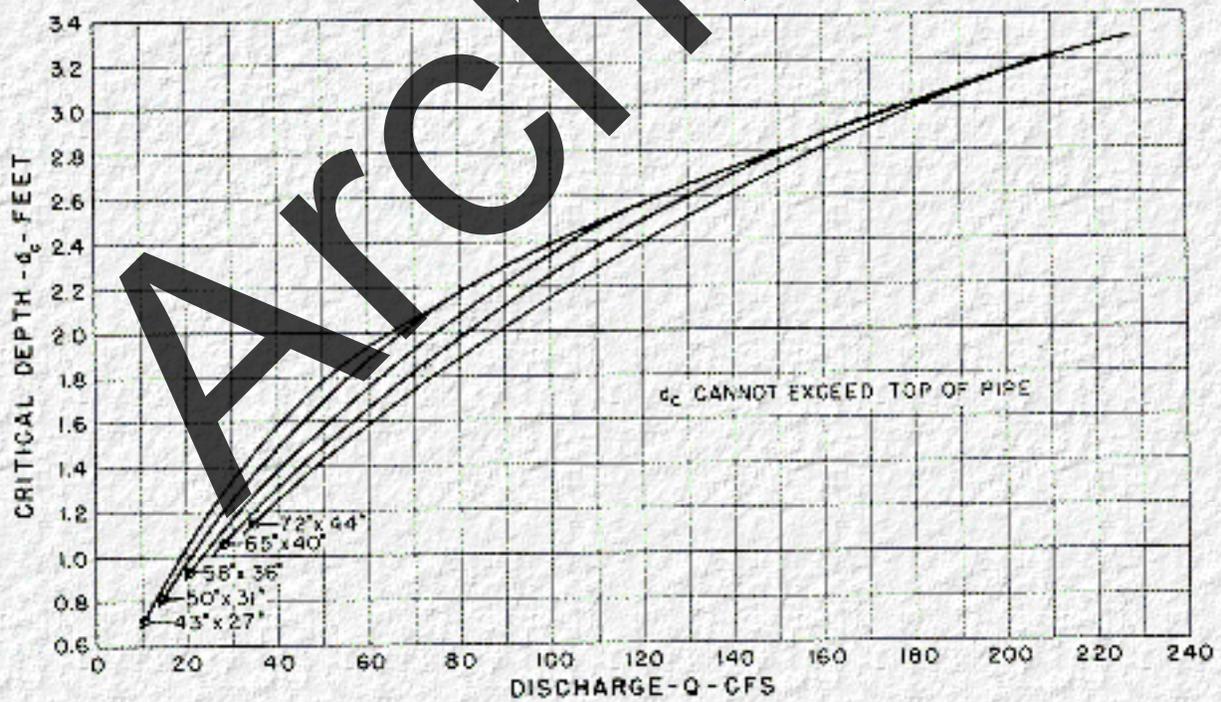
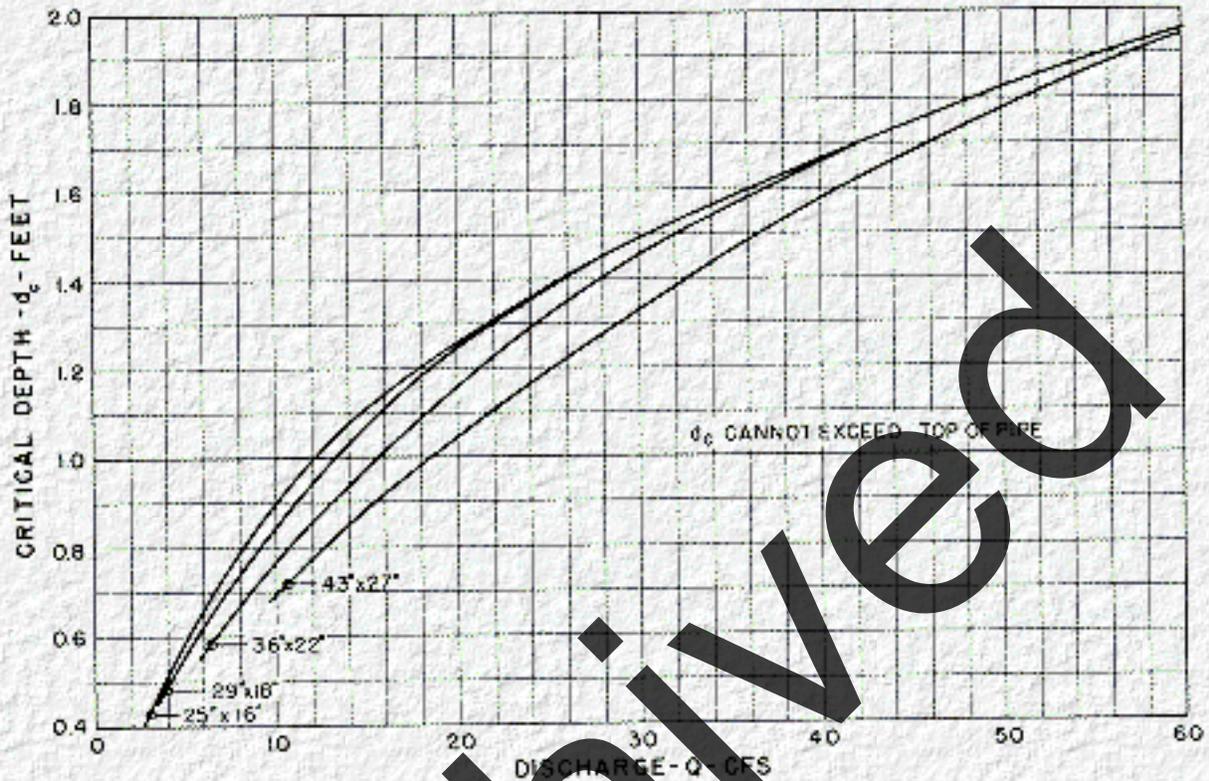
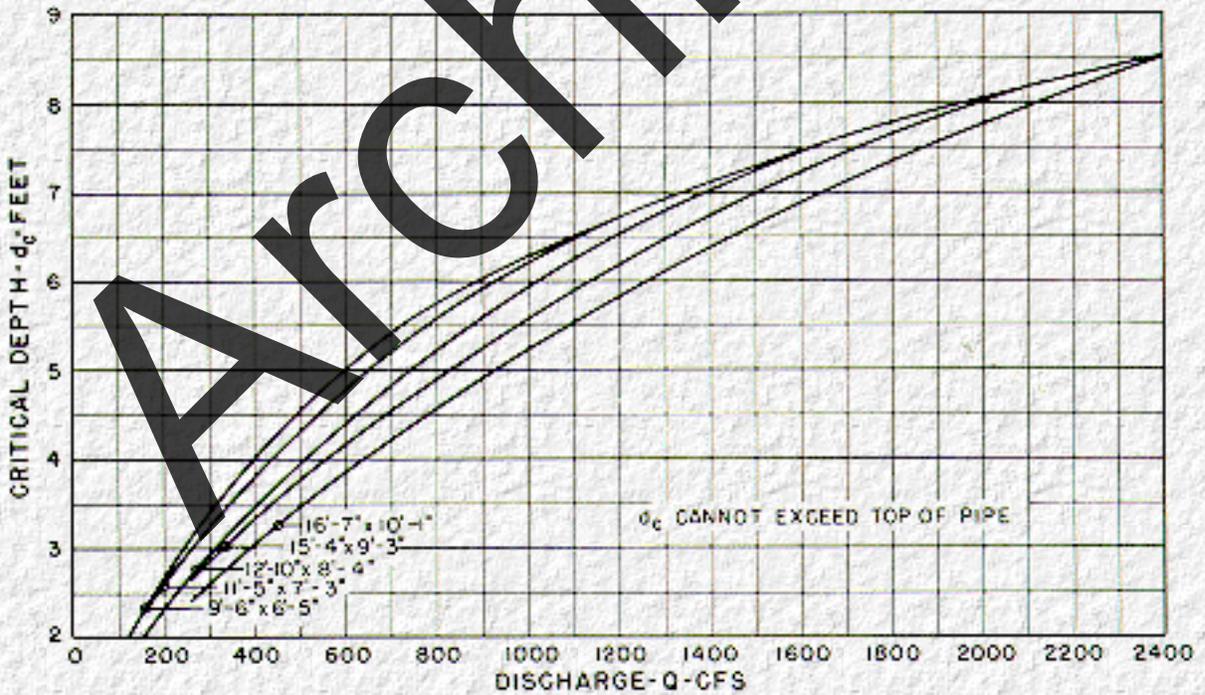
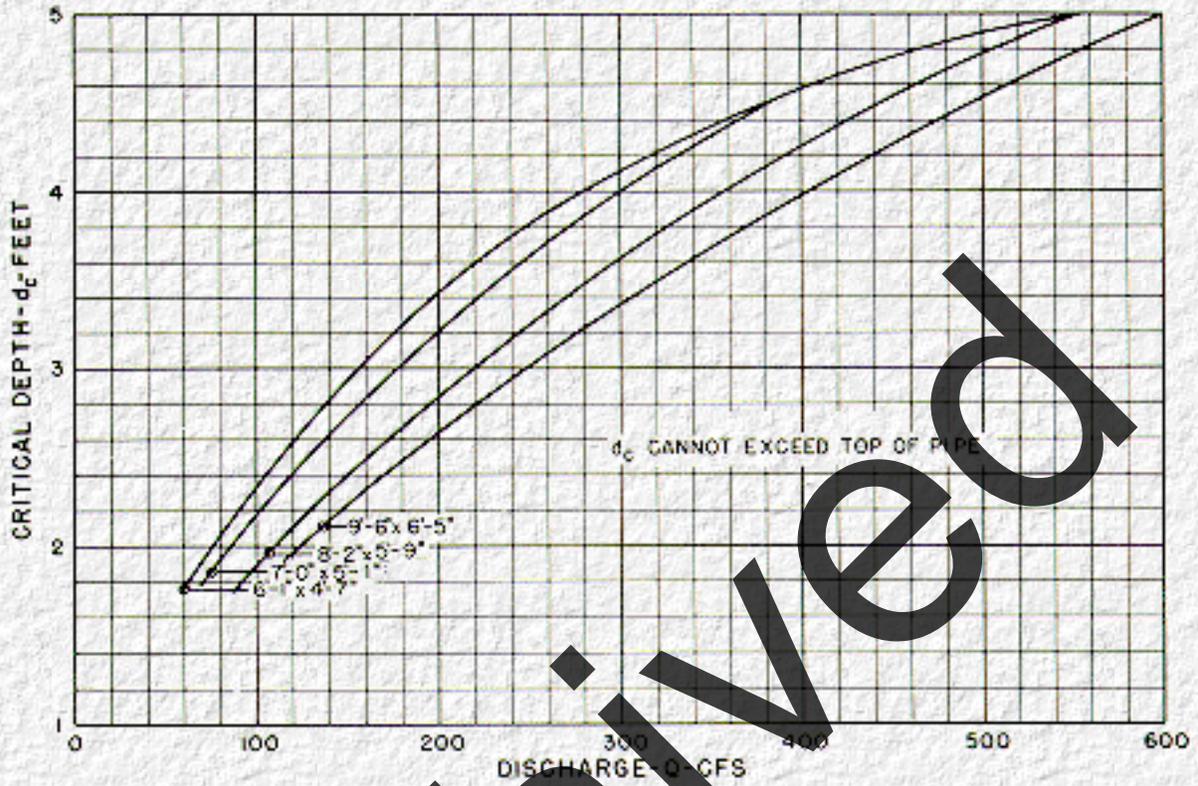


CHART 20



BUREAU OF PUBLIC ROADS
JAN 1964

CRITICAL DEPTH
STRUCTURAL PLATE
C. M. PIPE-ARCH
18 INCH CORNER RADIUS

CHART I

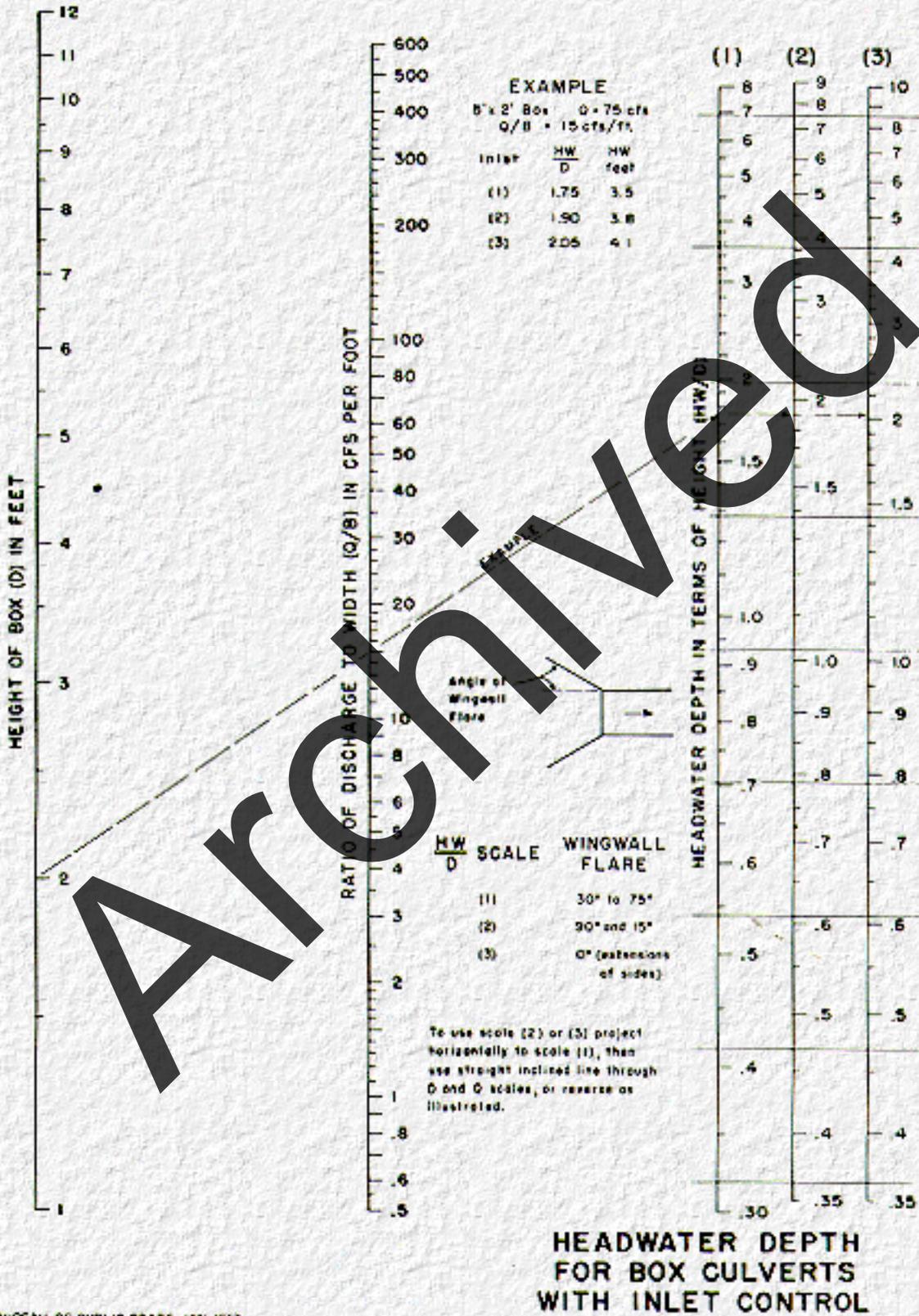
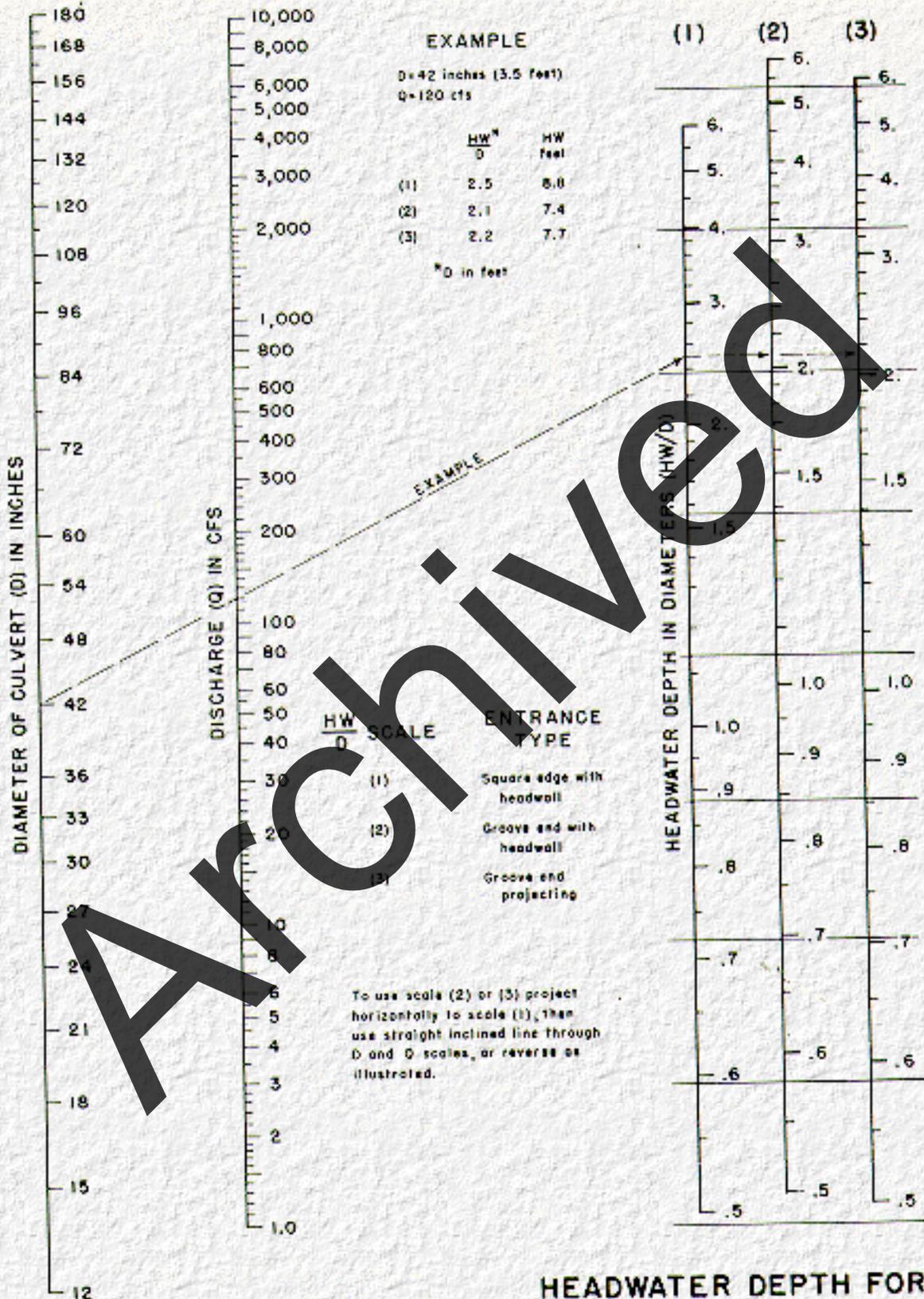


CHART 2

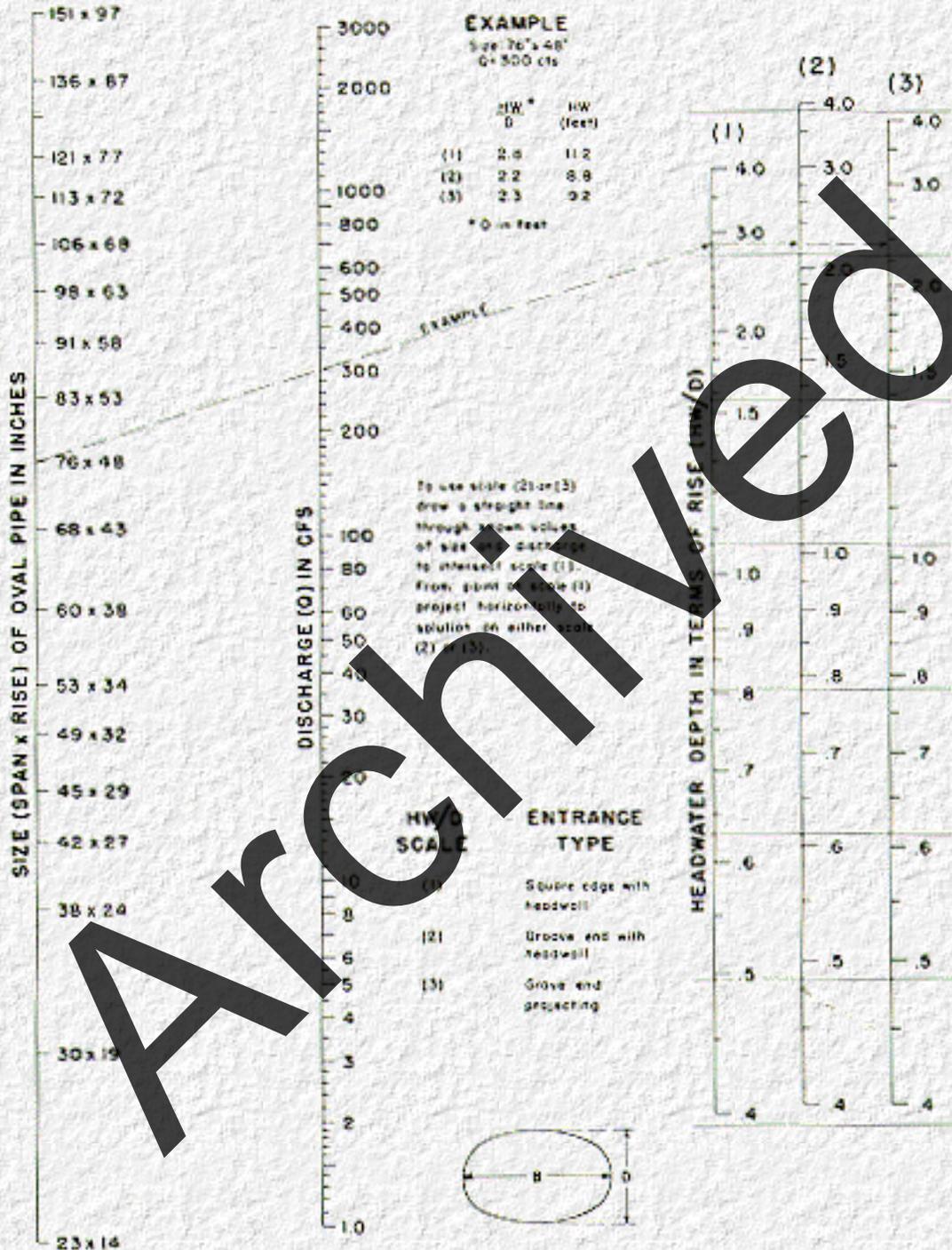


HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

HEADWATER SCALES 283
 REVISED MAY 1964

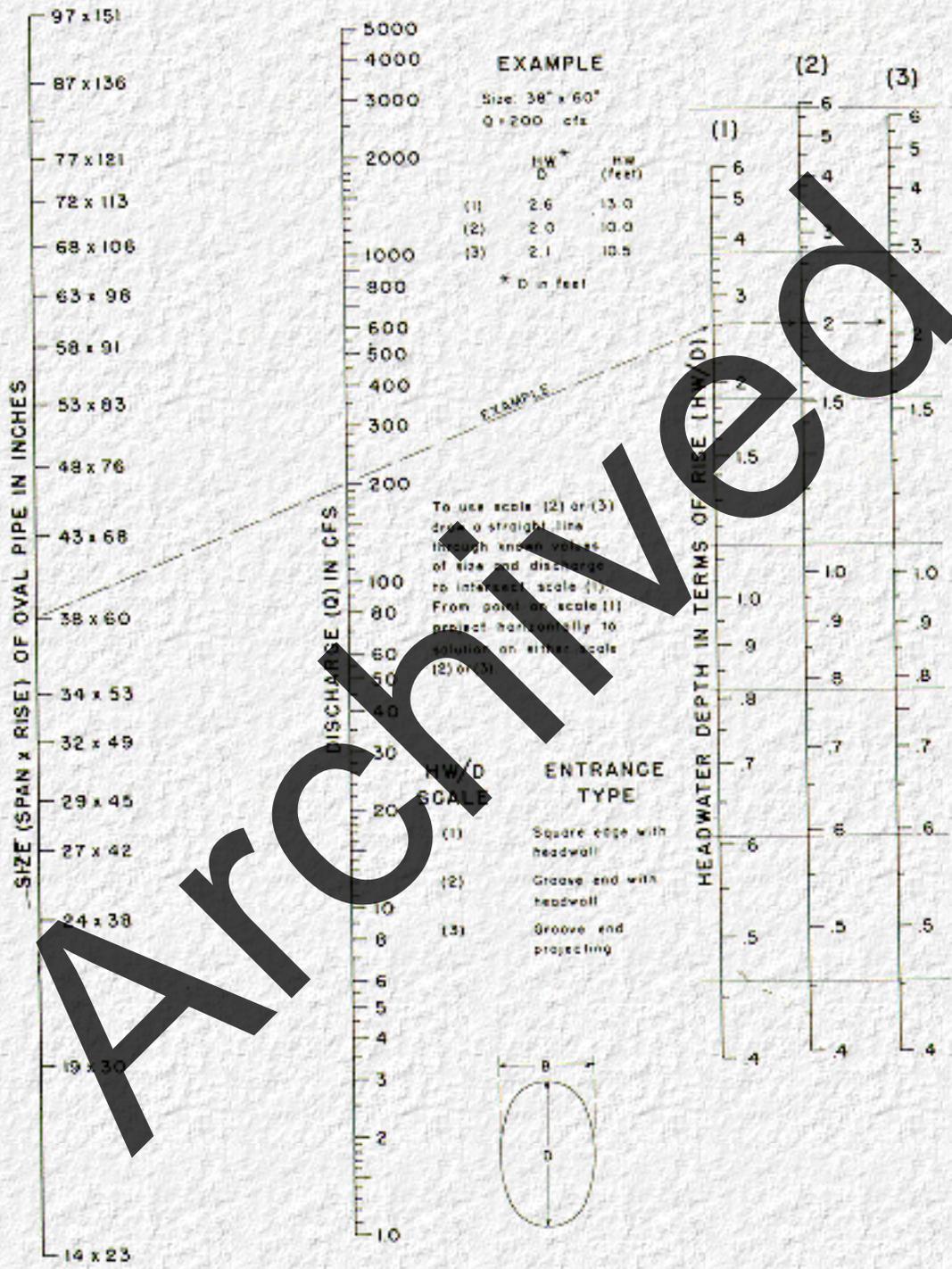
Archived

CHART 3



HEADWATER DEPTH FOR OVAL CONCRETE PIPE CULVERTS LONG AXIS HORIZONTAL WITH INLET CONTROL

CHART 4



HEADWATER DEPTH FOR
 OVAL CONCRETE PIPE CULVERTS
 LONG AXIS VERTICAL
 WITH INLET CONTROL



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[Table 1. Entrance Loss Coefficients](#)



[Table 2. Manning's n for Natural Stream Channels \(Surface width at flood stage less than 100 ft.\)](#)



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